STUDY OF LAND SUBSIDENCE BY INSAR TIME SERIES OF ALOS-2, SENTINEL-1 AND GNSS CORS STATIONS IN CHAOPRAYA BASIN, SAMUTPRAKAN, THAILAND

ADISORN SITTIWONG

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE MASTER DEGREE OF SCIENCE
IN GEOINFORMATICS
FACULTY OF GEOINFORMATICS
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การศึกษาการทรุดตัวของจังหวัดสมุทรปราการ ด้วยข้อมูลอนุกรมเวลาโดยใช้ข้อมูลดาวเทียม ALOS-2 Sentinel-1 และสถานี CORS

อดิสร สิทธิวงษ์

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรวิทยาศาสตรมหาบัณฑิต
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2565
ลิขสิทธิ์เป็นของมหาวิทยาลัยบูรพา

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The Thesis of Adisorn Sittiwong has been approved by the examining committee to be partial fulfillment of the requirements for the Master Degree of Science in Geoinformatics of Burapha University

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ADISORN SITTIWONG : STUDY OF LAND SUBSIDENCE BY INSAR TIME SERIES OF ALOS-2, SENTINEL-1 AND GNSS CORS STATIONS IN CHAOPRAYA BASIN, SAMUTPRAKAN, THAILAND. ADVISORY COMMITTEE: TIMO BALZ, Ph.D., PHATTRAPORN SOYTONG, Ph.D. 2022.

Samutprakan province is one of the economically most important provinces in Thailand. The province is located in the northern gulf of Thailand near Bangkok. This province is facing flooding from sea level rise. This problem is getting closer to the capital city: Bangkok. Samutprakan and surrounding provinces are facing sea level rise, flooding, and land subsidence. The land subsidence is an important factor of flooding in Samutprakan, shown by case studies showing that the land subsidence in Samutprakan is caused by many factors such as the use of ground water, land reclaiming, and movements of the Earth surface. The Department of Groundwater Resources started to do research between 1978 - 1981 and they found land subsidence of more than 10 cm per year in Bangkok and Samutprakan. After that, the study of land subsidence has been widespread to many Universities in Thailand such as King Mongkut University of Technology vicinity (Bangmod), Chulalongkorn University, and Kasetsart University to work on monitoring land subsidence in the central part of Thailand.

This study will identify the movement ratio of land subsidence rate in the last six years by using Interferometric Synthetic Aperture Radar; InSAR time series technique from ALOS-2 satellite, Sentinel-1 and Precise Point Positioning (PPP) from GNSS CORS stations to identify the rate of land subsidence and compare the land subsidence with three difference methods above in last 6 years of Samutprakan province Thailand.

The InSAR time series technique has been used for many decades to measure earth surface deformation with high resolution and high accuracy. The InSAR time series will correct data by using radio detection and ranging (RADAR) to send electromagnetic wave to object to the earth surface and reflect to satellite’s

antenna itself. The satellite images will be collected by sun-synchronous orbit satellite in many modes of transmission such as HH, VV, HV, VH and from ascending and descending orbits. Many scenes of satellite images in s time series will be processed by interferometric phase measurements which wrapped and unwrapped phases and compared with many scenes of images to find the subsidence rate of objects on earth surface with high accuracy number in millimeter.

The Precise Point Positioning (PPP) and GNSS stations Continuously Operating Reference (CORS) or a permanent GNSS satellite receiver station. These stations receive signals 24 hours a day, 365 days a year to use the information that obtained to refer to the coordinates. It is a reference station for RTK (Real-Time Kinematic) and Network RTK (VRS) surveys. All data will be combined before PPP processing to remove GNSS errors and get the highest position accuracy from one receiver. Accuracy data from many stations and many times will be presented the difference of GNSS CORS stations in Latitude, Longitude, and Height to present the difference numbers of time series.

Both techniques are used to identify data from difference sources to find the subsidence rates of the study area in Samutprakan, in order to allocate the suitable area for industrial constructions and farming areas. The result from this thesis will benefit the residents in Samutprakan and the planning of industrial areas in the next 6 to 12 years and indicate the most accuracy methods from these three methods.

ACKNOWLEDGEMENTS

For a very good opportunity to get the scholarship from Thai government: the Ministry of Higher Education, Science, Research and Innovation, Thailand and have a good change to study in Wuhan University: China, Burapha University: Thailand, and Geo-Informatics and Space Technology Development Agency (Public Organization) GISTDA (under Ministry of Higher Education, Science, Research and Innovation: Thailand) to offer Double master's degree on Geo-Informatics and Space Technology. This thesis pushes me up to higher skills and gained new knowledges from the world class institute like the State Key Laboratory of Information Engineering in Surveying, Mapping and Remote Sensing, Wuhan University (LIESMARS). In the please, I have learnt from the professional in field of SAR and high technology of SAR software, SARPORZ that can detect land subsidence in millimeter by satellite data with all-day all-night survey by RADAR of satellite. For my two years of master study, I have gained from many persons. It is my pleasure that would like to express my gratitude to all of them. First, I would like to thank and appreciate my supervisor Prof.Dr.Ing- Timo Balz, Dr Phattraporn Soytong, Dr. Anuphao Aobpaet, Dr. Kitsanai Charoenjit. I would also thank you to my classmates, SCGI batch 3, Master Program Student and the other members of my Master's, Ph.D. classmate and SAR team in Faculty of Geoinformatics, Burapha University and State Key Laboratory of Information Engineering in Surveying, Mapping and Remote Sensing, Wuhan University. The source of data of this research consists of Department of Public Works and Town & Country Planning (DPT), Department of Land (DOL), Kasetsart University, Sentinel-1 website, and AUSPOS online software. Finally, I will bring all knowledge and new technology back to Thailand to distribute for people who interested in remote sensing and geoinformatics in Thailand for further study in the future.

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ALD	Azimuth Look Direction
AOI	Area of Interesting
APS	Atmospheric phase screen
ASC	Ascending orbit
ASI	Agenzia Spaziale Italiana (Italian Space Agency)
BMA	Bangkok Metropolitan Administration
BPLE	Depart of Lands
CGPS	Continuous Global Positioning System
CONAE National	Comisio ´n Nacional de Actividades Espaciales (Argentina - Space Activities Commission)
CORS	Continuously operating reference station
DCP	Department of City Planning
DEM	Digital Elevation Model
DES	Descending orbits
DPT	Department of Public Works and Town & Country Planning
DInSAR	Difference Interferometric Synthetic Aperture Radar
DLR	Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Centre)
DOI	Date of interest
ERS	European remote sensing satellite
ESA	European Space Agency
EW	Extra-Wide swath

GCP	Ground control point
GIS	Geographic Information Systems
GISTDA	Geo-Informatics and Space Technology Development Agency
GNSS	Global Navigation Satellite System
InSAR	Interferometric Synthetic Aperture Radar
IW	Interferometric Wide Swath
JAXA	Japan Aerospace Exploration Agency
LOS	Line-of-sight
MSL	Mean Sea Level
PSCs	Permanent Scatterers candidates
PS-InSAR	Persistent Scatterer Interferometry Synthetic Aperture Radar
RADAR	Radio Detection and Ranging
SALT	Satellite Altimeter
SAR	Synthetic Aperture Radar
SB/SBAS	Small Baseline
SCGI	Sirindhorn Center of Geo-Informatics
SLC	Single-Look Complex
SM	Strip Map
SRTM	Shuttle Radar Topography Mission
StaMPS-MTI	Stanford Method for Persistent Scatterers - Multi-Temporal

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TOPS	Terrain Observation with Progressive Scans
VV	Vertical-Vertical Polarization
WV	Wave

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LIST OF SYMBOLS

ϕ	Phase
λ	Wavelength
θ	Incidence Angle
$\Delta\phi$	Interferometric phase (or phase difference)
ϕdef	Phase contribution related to ground deformation
ϕorbit	Orbit Error
ϕtopo	Topographic Effect
ϕnoise	Noise
ϕatm	Atmospheric Delay
ϕ1, ϕ2	Phase of each acquisition
Δr	Difference in range (LOS) between two SAR acquisitions
dLOS	Deformation along line of sight (LOS)
dVert	Vertical motion
dHALD	Horizontal in descending ALD
$\Delta\alpha$ and	Difference of the heading satellite between ascending descending orbits
σ	Standard deviations

CHAPTER 1: INTRODUCTION

1.1 Background and Problem statement

Samutprakan province is the most important industrial province and one of the main ports of Thailand, located in the north coast of Thailand near Bangkok. This area is receiving the impact of climate change from sea level rise and land subsidence, caused by many factors such as use of ground water from many industries in this province and surrounded area, the movement of earth surface and the numerous constructions in this area. This study will identify the movement ratio of land subsidence rate in last six years by using Interferometric Synthetic Aperture Radar (InSAR) time series technique from ALOS-2 satellite, Sentinel-1 and Precise Point Positioning (PPP) from GNSS CORS stations to identify the rate of land subsidence and compare the land subsidence with three difference methods above in last 6 years of Samutprakan province Thailand.

The InSAR time series technique has been used for many decades to measure earth surface deformation with high resolution and high accuracy. The InSAR time series will correct data by using radio detection and ranging (RADAR) to send electromagnetic wave to object to the earth surface and reflect to satellite's antenna itself. The satellite images will be collected by sun-synchronous orbit satellite in many modes of transmission such as HH, VV, HV, VH and ascending, descending modes. Many scenes of satellite images in time series will be processed by interferometric phase measurements which wrap and unwrapping phase and compare with many scenes of images to find the subsidence rate of objects on earth surface with high accuracy number in millimeter.

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Both techniques are used to identify data from difference sources that mention above to find the subsidence rates of study area in Samutprakan in order to allocate the suitable area for industrial constructions, land use farming area in the study area. The result form this thesis will be benefits for the residents in Samut prakan and industrial area to plan for suitable area of their purposes in the next 6 to 12 years and indicate the most accuracy methods from these three methods form this thesis.

1.2 Problem Statement

The land subsidence is very important for study because there many earth's plates throughout the world are facing the cases of land subsidence every year. Thailand is also facing the land subsidence. For this study directly focused on Samutprankan, the coastal province near Bangkok that is facing flooding from sea level rise and land subsidence. This study is trying to find the specific area in Samutprakan to be benefits of the residents in this area to plan their land use in the future. For the history of land subsidence study presented that the Department of Groundwater Resources has started to do research from 1978 - 1981 and they found the land subsidence rate more than 10 cm per year in Bangkok and Samutprakan. After that, the study of land subsidence has been widespread to many Universities in Thailand such as King Mongkut University of Technology vicinity (Bangmod), Chulalongkorn University, and Kasetsart University to work hard for monitoring land deformation in the central part of Thailand and other provinces.

The main factor of land subsidence in Samutprakan is the use of ground water for many industries because fresh water is very important for living things and industries throughout the area. The Chaopraya river cannot support fresh water for the need of their residents. It means that the ground water is very important for people in this province. The land subsidence is going to be one of problem in Samutprakan because the use of ground water and movement of Earth surface are leading the ground level lower every year according to many case studies.

Therefore, the land subsidence in Samutprakan is very important to study because we can predict and measure the velocity of land deformation. The trend of land subsidence will provide information to the residents to have awareness for the area that got high rate of land subsidence. To study land subsidence, the high and famous technology is the Persistent Scatterer Interferometry Synthetic Aperture Radar (PS-InSAR) that will be the main technology of this study.

1.3 Research Motivation

Synthetic Aperture Radar (SAR) offers high spatial resolution for land subsidence monitoring with the capability of Radar from satellites to observe and receive Earth data without the limit of weather and night-time. SAR satellites is very useful for military observation ground deformation and so on that can detect objects on earth surface with Radio Detection and Ranging (RADAR). The SAR satellite normally are placed in sun synchronous orbits that will shift follow the Earth move around the Sun. In the is research uses ALOS-2 and Sentinel-1 that are the most famous SAR imagery date for land subsidence. The PS-InSAR is the main method of the land subsidence that can detect high precision of land deformation.

Sentinel-1 and ALOS-2 are the best provider date of SAR images to study land subsidence. The sentinel-1 started to launch data for researchers from 2014 until nowadays with 12 days revisit time. The data of Sentinel can be download freely from their official website with satellite images and SAR images. The ALOS-2 is the high technology satellite provide data and images from 2014 with 14 days revisit time.

CORS stations are the GNSS static antenna with base stations can measure and provide benchmark for satellite from geo stationary orbits and other satellites. The CORS stations will move follow the Earth surface because the station itself located over the ground in x y and Hight.

All the data from two satellites, CORS stations and PS-InSAR technique are the main factor of study of land subsidence in Samutprakan to show the different way of three sources of data that will present land deformation of study area.

1.4 Research question

What are the main factors of subsidence that influence/induce in Samutprakan province?

What is the land subsidence rate in study area per year?

What are the differences between the three sources, ALOS-2, Sentinel-1, and CORS stations, in their results of land subsidence?

1.5 Research Objective

This research mainly focusses on land subsidence in Samutprakan province, Thailand, to find the different ground level changes by time series from 2014 to 2020. This research will use three different sensors consist of ALOS-2, Sentinel-1, and two CORs stations in study area to identify the movement ratio of land in Samutprakan by using those different sensors. The three different sensors will provide different kinds of data set as satellite images by Interferometry synthetic-aperture radar (InSAR) from ALOS-2 and Differential SAR Interferometry (DInSAR) from Sentinel-1. The CORs station provide data set in term of GNSS ground stations that are calibrated by many GNSS satellites. They provide the land movement or land subsidence in horizon and vertical directions. In this research will study the land subsidence in Samutprakan province that is the one of the highest risks to be flooded in few decades (Yutaro Shimada, 2021) from sea level rise, ground sources pump, and land subsidence by industrial constructions and the use of ground water according to the growth of economy zone rapidly in this province.

1) To identify the movement ratio of land in Samutprakan in last six-year 2014 to 2020 with GNSS and InSAR time series of ALOS-2 and Sentinel-1 data.

2) To predict the movement of land in Samut prakan in next 6 years using Precise Point Positioning (PPP) and InSAR time series.

3) To find the most suitable method that measure the highest accuracy land subsidence.

1.6 Contribution of knowledge

Samutprakan province has been facing the land subsidence long time ago since the study in early 1970 (Haley and Aldrich Inc., 1970; Brand et al., 1971; and Edward, 1976). Moreover, land deformation and related factors have been analyzed, including the use of groundwater, crustal deformation, urban construction, aquifer structure, active faults, land uses types, and soil thickness. These factors present similar effects on many urban areas. These are the reasons why this research considers the scientific question: What are the main factors of subsidence that influence/induce in Samutprakan by study of Sentinel-1 and ALOS-2 satellite image? How do GNSS can represent and support land subsidence from static base stations. Therefore, this study aims to apply the PS-InSAR time series technique to measure the land subsidence of Samutprakan province using Sentinel-1 satellite data and ALOS-2 satellite data between 2014 - 2020. The study area is approximately 5,000 km^2 as cover Samutprakan also some part of Bangkok, Pathum Thai, Nonthaburi province.

To investigate and measure the subsidence (2014-2020) in Samutprakan using Persistent Scatterer Interferometric Synthetic Aperture Radar (PS-InSAR) time-series method (Ferretti et al., 2001; Hopper et al., 2006) was performed with 22 Sentinel-1 and 30 ALOS-2 earth surface Observation by Progressive Scans (TOPS) mode SAR data and SLC. These data cover global area and has revisit time 12 days and 14 days respectively. At the same time, the SAR data is available all-day, and all night also provide the advantage of weather independence that is suitable for most weather conditions. The PS-InSAR time-series techniques can detect ground subsidence movement with relatively high precision at millimeter variations in the line-of-site velocity (Perissin, 2008) and consist of pre-processing data, SAR processing, PS-InSAR processing, multi-image PS-InSAR processing, and persistent scatterer processing. The PS-InSAR subsidence rate was analyzed using ground subsidence rate from leveling benchmarks of two GNSS CORS stations to validate and provide accuracy results for this research.

Due to the land subsidence that occur throughout the Earth surface, this research will give the results and useful information to make a comparison to other research or provides the useful information to the authority concerned in Thailand for further plan of land use. The results that have been shown would be beneficial not only the long-term study but also benefit for people in the study area to make their plan for land use in the next 6 to 12 years from these results. Moreover, these results would help government sector to understand the trend of land subsidence in Samutprakan province that they can stop or hold some mega projects the use of ground water that will get some effect or huge damages from land subsidence in Samutprakan province.

CHAPTER 2: LITERATURE REVIEW

The area of study in this research mainly focusses on Samutprakan province because this area is very important and located very close to the capital city of Thailand, Bangkok. This area is receiving the impact of earth surface movement, sea level rise, and land subsidence form many factors such as use of ground water from many industries in this province and surrounded area, the movement of earth surface and the many constructions in this area. The research questions are: What is the land subsidence rate in study area per year? What is the most suitable method that measure high accuracy land subsidence? This study will identify the movement ratio of land subsidence rate in last six years by using Interferometric Synthetic Aperture Radar; InSAR time series technique with ALOS-2 satellite, Sentinel-1 and Precise Point Positioning (PPP) from GNSS CORS stations to identify the rate of land subsidence and compare the land subsidence with three difference methods above in last 6 years of Samutprakan province Thailand.

2.1 Land Subsidence study In Thailand

Bangkok with 53 their cities has changed rapidly during the past 50 years on both banks of the river. It covers area of land deformation around 4,200 km². The flooding area approximately 58 city every year. (Phien-wej, N. & Giao, P. & Nutalaya, P.,2006)

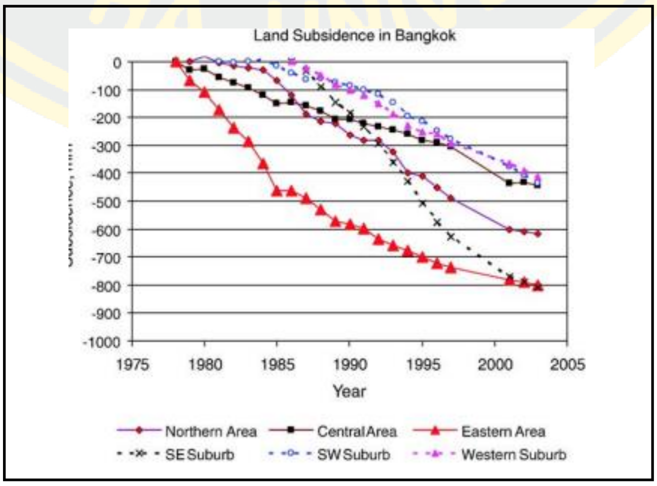

Figure 1 Land subsidence versus time in different areas of Bangkok. (Phien-wej, N. & Giao, P. & Nutalaya, P.,2006)

This study on figure shown that Bangkok has some gradually land deformation for long time ago, but never been study before since the human created InSAR technology to study land subsidence in the past 50 years.

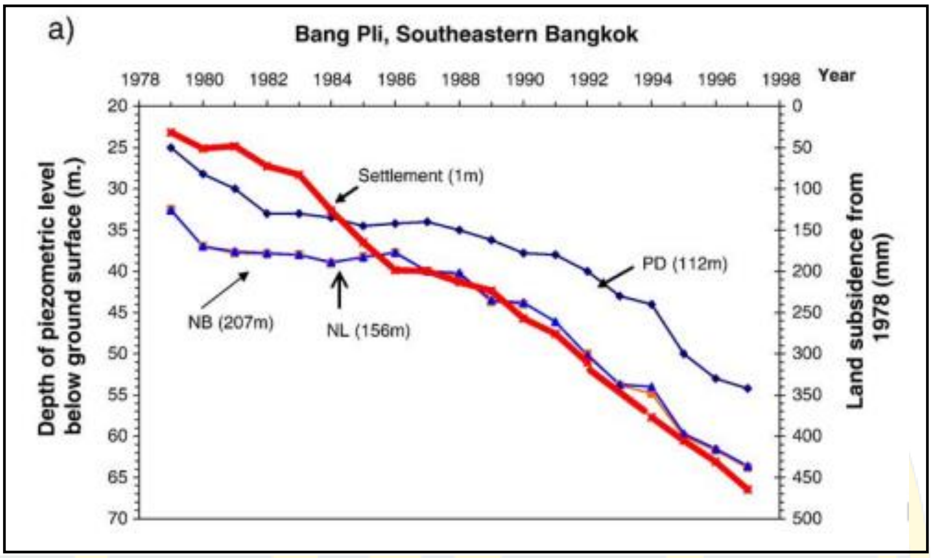

Figure 2 The land deformation and piezometric drawdowns of aquifers by time series. (Phien-wej, N. & Giao, P. & Nutalaya, P.,2006)

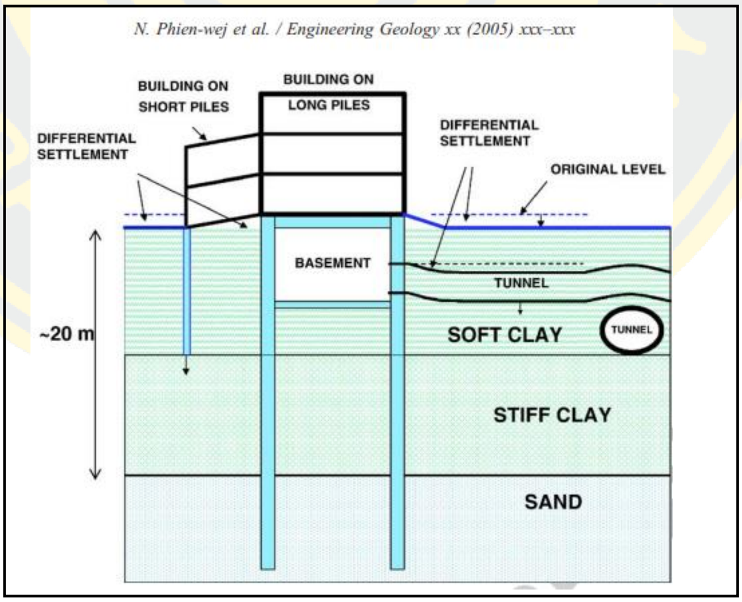

Figure 3 The pattern of differential settlements caused by land subsidence in Bangkok and provinces surrounded. (Phien-wej, N. & Giao, P. & Nutalaya, P.,2006)

In the figure 3 presented that the soil of Samutprakan consist of many layers of clays and sand. It means that the lower layer of central part of Thailand mostly is clay and sand. This is to support reason for land deformation in the central part of Thailand.

Aobpaet, A. (2021) The latest study in Bangkok and surrounded province has shown the interesting statistic that the land subsidence rate is from -34.20 to +35.70 mm per year. This study indicated that the land deformation consists of high range by time to time from October 2018 to May 2019 (7 months). The wide range of land movement in Bangkok and Samutprakan has relative relationship by statistic above.

2.2 GNSS CORS station in Thailand

The Precise Point Positioning (PPP) and GNSS stations Continuously Operating Reference (CORS) or a permanent GNSS satellite receiver station. (Lia, Shusen Wanga, Cassandra Michelb, Hazen A.J. Russell. 2020) These stations receive signals 24 hours a day, 365 days to use the information obtained to refer to the coordinates. It is a reference station for RTK (Real-Time Kinematic) and Network RTK (VRS) surveys. All data will be combined before PPP processing to remove GNSS errors and get the highest position accuracy from one receiver. Accuracy data from many stations and many times will be presented the difference of GNSS CORS stations. In this technique is very important to identify the position accuracy from earth surface in horizontal direction and vertical direction. That is another method to compare all data for the most accuracy result of land subsidence. Somchai K. (2021) The estimates station coordinates of GNSS CORS networks in Thailand 285 stations cover Thailand region can provide real-time dynamic framework with higher accuracy. The CORS stations are the reference station to calculate grid coordinate related to GPS services.

Figure 4 CORS station in Thailand, March 2022 (geoportal.rtsd)

For this research two CORS stations located in Samutprakan from the Department of Lands and Department of Public Works and Town & Country Planning are being used. CORS data from both stations provide data for this research from 2014 – 2020 with RINEX files of GNSS data.

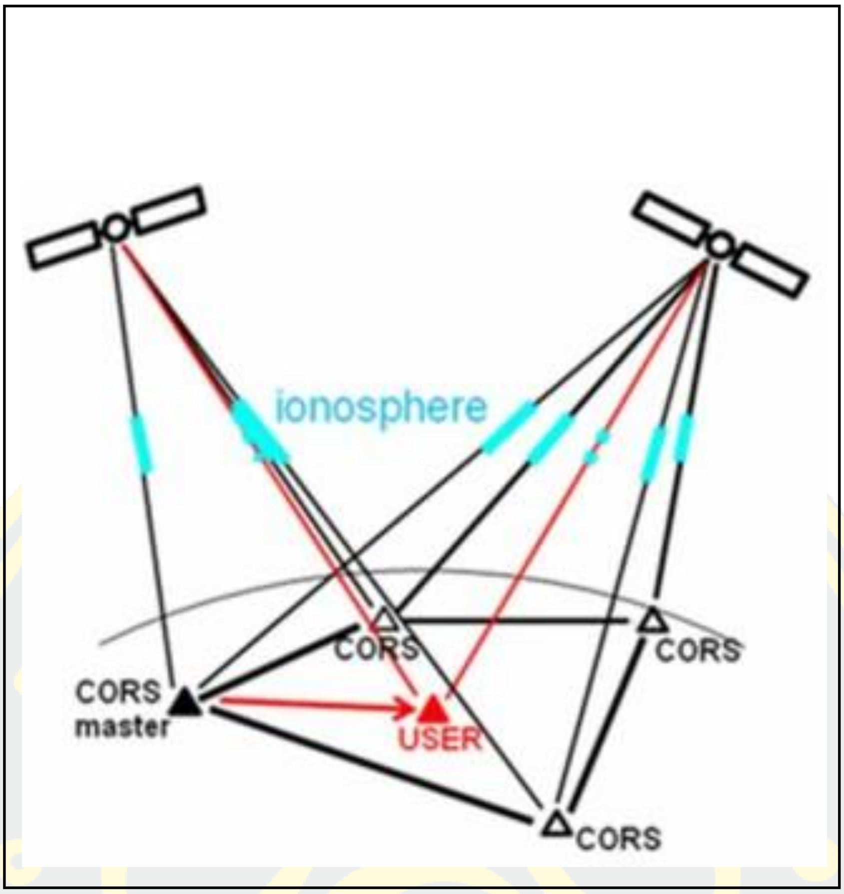

Figure 5 CORS station with their functions (gnss.curtin.edu.au

2.3 Precise Point Positioning

Precise Point Positioning (PPP) is the technique that remove some error of GNSS data. The PPP technique can be accurate less than 3 cm by removing atmospheric conditions, multipath environment, and satellite geometry. The PPP services provide in many types of satellites such as TerraStar, OmniSTAR and StarFire. (novatel.com)

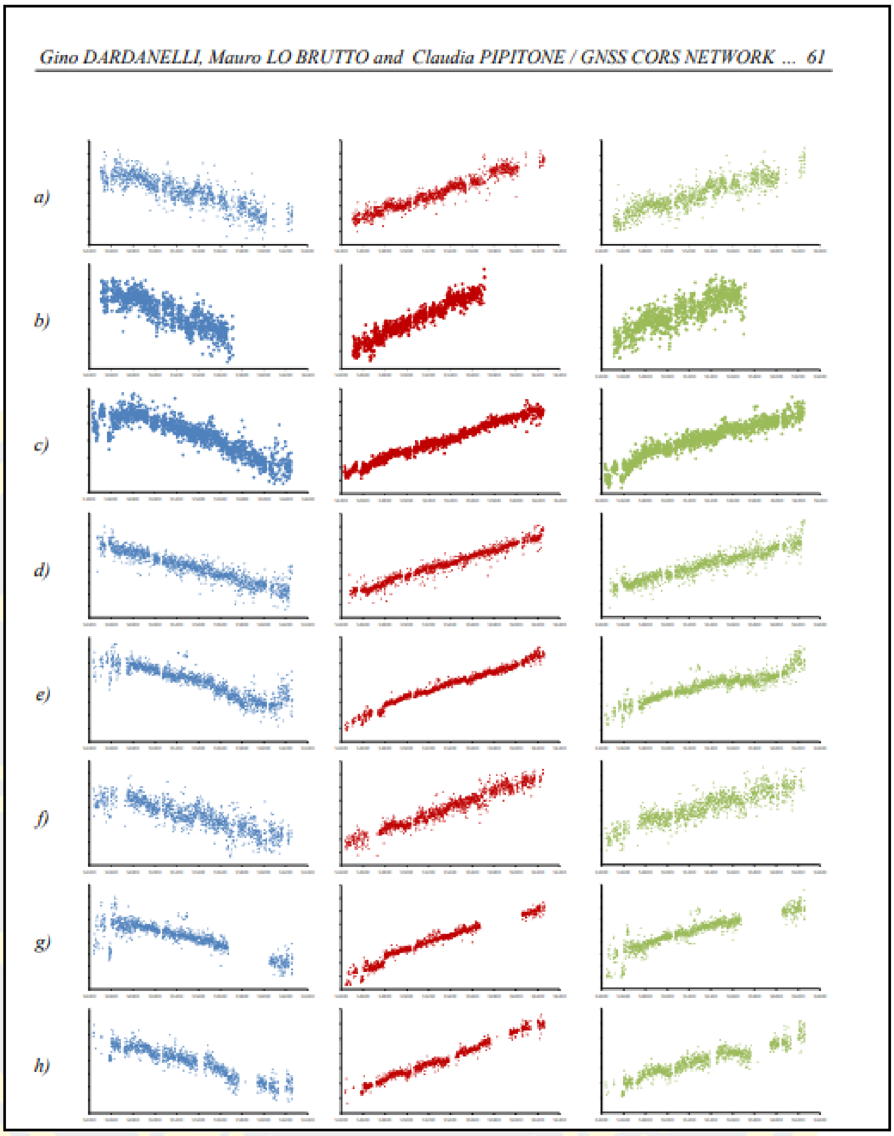

Figure 6 time series diagram of CORS stations a to h in Italy

2.4 InSAR Time series

Land subsidence is commonly use InSAR Time series technique to analysis the InSAR data in order to analysis and measure the displacement of the Earth surface. (El Kamali, Abdelgadir Abuelgasim, 2020), (Bo Hu, Junyu Chen and Xingfu Zhang. 2019) The study of Changes in the Earth's surface such as earthquakes, volcanoes, and land subsidence use InSAR timeseries. Time series analysis is applied to interferometric phase measurements, which wrap around when the observed motion is larger than one-half of the radar wavelength. Thus, the spatial temporal "unwrapping" of phase observations is necessary to obtain physically meaningful results. Many different algorithms have been improved for time series analysis of InSAR data to remove all the ambiguity. However, there is no single algorithm that can provide optimal results in all cases. After the time series analyses of InSAR data are used in many ways of applications with different characteristics, each algorithm possesses inherently unique strengths and weaknesses. In This research will use this technique to identify land subsidence by using ALOS-2 and Sentinel-1 data and make comparison for the best resolution from both data set.

Permanent Scatterers InSAR (PSInSAR) technique is the improvement of DInSAR. This method uses coherent radar targets that can be clearly classified in all data images and do not vary in their properties (Ferretti et al., 2001). Based on their permanent properties they are called permanent scatterers that uses permanent scatterers, the atmospheric effects will be cleared out and the temporal and geometrical decorrelation will be removed. The drawback of this method is a loss of data continuity. The data are a set of points with a density depending on the form and coverage of the surface. These coherent radar targets are abundant in urban areas but are very scarce in the vegetated and mountainous areas. The theoretical background of interferometry has been known for more than two decades and the first successful interferometric analysis was conducted (Zebker in Goldstein, 1986). The real breakthrough in the field of interferometry came in 1991 with the launch of the first European satellite for Earth observation, the ERS-1.

2.6 Sentinel-1

The Sentinel-1 mission is the cooperation between the European Space Agency (ESA) and European Radar Observatory for the Copernicus joint initiative of the European Commission (EC). This mission is dealing with Earth observation for environment and security. It receives data from Earth Observation satellites and ground-based information. The Sentinel-1 mission provides C-band imaging with different resolution that can be down to 5 m and coverage up to 400 km. It provides dual polarization capability with 12 days revisit times and send product delivery rapidly. For observation, the Sentinel-1 will precise measurements of spacecraft position and attitude are provided. The Synthetic Aperture Radar (SAR) has the highly advantage of its operation at wavelengths not impeded by cloud cover or a lack of illumination and can acquire data over a site during day or night-time under all weather conditions. Sentinel-1, with its C-SAR equipment can offer reliable, repeated wide area monitoring. The mission works with a constellation of two Satellites; Sentinel-1A and 1B that are sharing the same flying orbit. The Sentinel-1 satellite can work by pre-programmed imaging all global landmasses, coastal zones and shipping routes at high resolution, conflict-free operation mode, and covering the global ocean with vignettes. This mission can provide the data services with long term series of the new technology. (sentinels.copernicus.eu)

Interferometric Wide Swath (IW)

The Interferometric Wide Swath (IW) can have swath width of 250 km with a medium resolution of 100 m^2. This mode is the most common use over the earth surface to detect a target on the land. The IW mode provides a ScanSAR mode named "Terrain Observation with Progressive Scans", TOPS shortened. This scanSAR mode helps us to reduce the drawbacks amount of using a ScanSAR mode by shrinking the pattern of azimuth antenna while the satellite goes along track direction. The antenna change position in the another direction of the Spotlight support for a good result. For the TOPSAR, that will get the same coverage and resolution like a ScanSAR in order to have it with approximately uniform SNR (Signal-to-Noise Ratio) and DTAR (Distributed Target Ambiguity Ratio). The TOPS mode will use a cycle rotation antenna in the azimuth direction. That is the same with the ScanSAR. At the same time, to reduce azimuth resolution as in the ScanSAR helps us to increase the swath coverage.

In IW GRD interferometry is completed by all overlap of the Doppler spectrum (in the azimuth domain) and their wave number spectrum (in the elevation domain) that will get the result of homogeneous image quality all the swaths. The Sentinel-1 C-SAR mode must use TOPS burst synchronization that the uses repeat-pass data-takes to support the generation of TOPS interferograms and coherent radar change detection. For the IW and EW modes the TOPS could be busted duration and ranges from 0.82 secs to 0.54 secs could be the worst-case scenario. The requirement of fast synchronization of less than 5ms will only occur between corresponding bursts operation. The TOPSAR requirement is that there is very high accuracy within the images co-registrations. If a small co-registration error occurs in the azimuth, it will provide an azimuth phase ramp due to the SAR antenna beam sweeping that causes the Doppler centroid overpass frequency variations of 5.5 kHz. (eos.com)

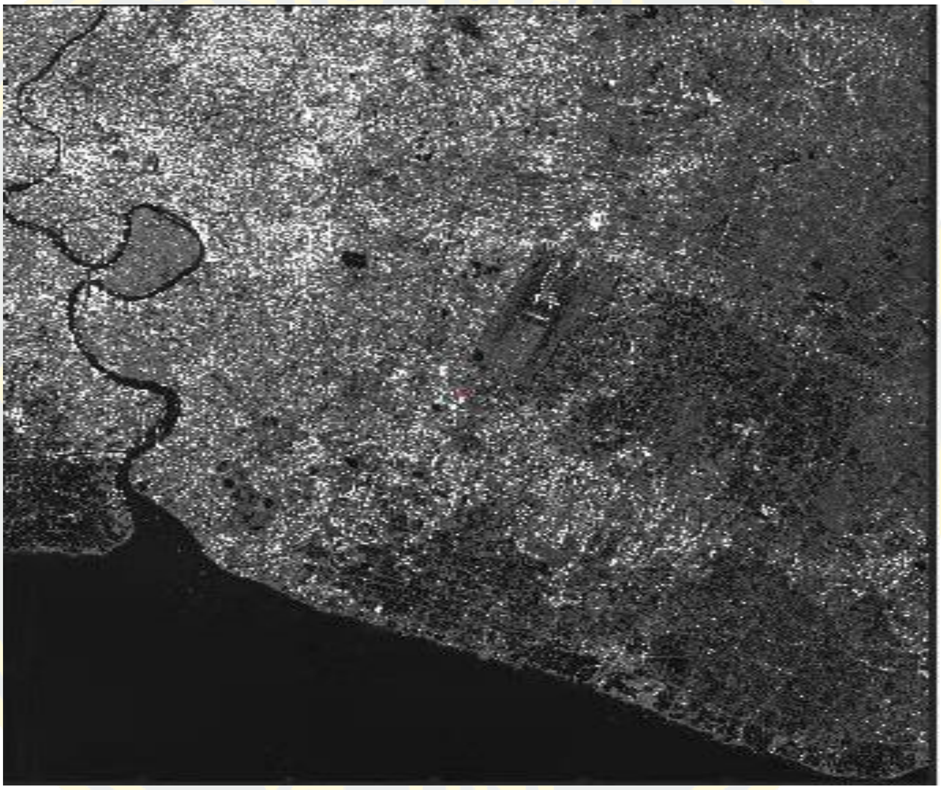

Figure 7 The mean of amplitude map using PS-InSAR (SARPROZ software)

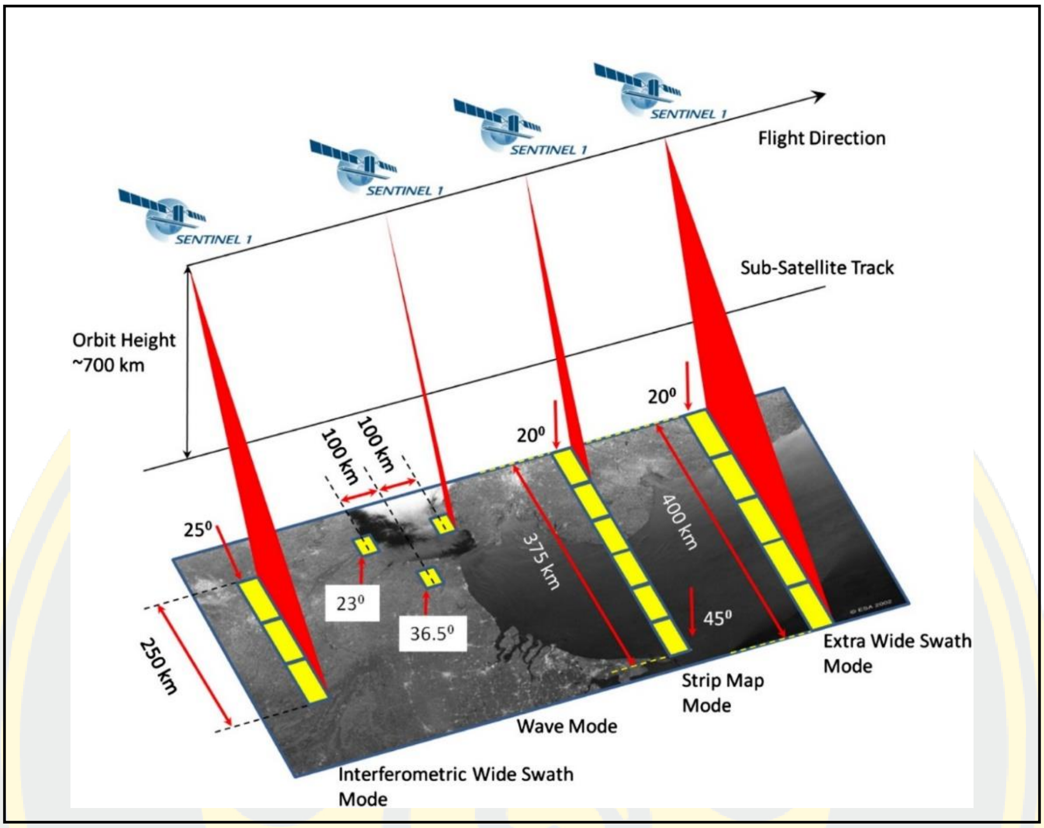

Figure 8 Sentinel-1 mission (sentinels.copernicus.eu)

2.7 Equation

The SAR system transmits the microwave pulse that consists of amplitudes and phases. The difference phases represent the Earth's surface movement by using the phase difference between two SAR acquisitions (Δϕ), as shown in Equation 1. Hence, Δϕ can calculate the ground surface movement in LOS of a satellite (Δr), but Δϕ is wrapped difference phase form. So, measuring the deformation, the interferometric phase needs to be unwrapped. Simultaneously, the fundamental InSAR principle is used differential SAR interferometry (DInSAR) by a spatial ground surface of a stable object. The phase difference (Δϕ) (A. Ferretti et al., 2001; Hanssen, 2001) as shown in Equation 2 is the summation of a phase of surface movement, or phase contribution of the pixel in the satellite LOS direction relate to ground deformation (ϕdef), phase of orbit error (ϕorbit), topographic effect phase (ϕtopo), phase of noise (ϕnoise), and atmospheric phase delay (ϕatm). The phase difference is calculated based on Equation 1 and Equation 2:

$$\Delta\phi = \phi 1 - \phi 2 = 4\pi\ \lambda\ \Delta r \qquad \text{Equation 1}$$

where

$\phi 1$, $\phi 2$: the phase of each acquisition

λ: wavelength of radar

Δr: the difference in range (LOS) between two SAR acquisitions

$$\Delta\phi = \phi atm + \phi def + \phi topo + \phi orbit + \phi noise \qquad \text{Equation 2}$$

where

$\Delta\phi$: interferometric phase (or phase difference)

ϕatm: Atmospheric Delay

ϕdef: phase contribution related to ground deformation

$\phi topo$: Topographic Effect

$\phi orbit$: Orbit Error

$\phi noise$: Noise

As shown in Equation 2, the interferometric difference phases are the sum of many natural phenomena such that errors in satellite position and topography alter deformation measurements. Furthermore, changing atmospheric conditions also degrade the deformation signal. Since 2000, many groups worked on mitigating these unwanted signals, using multiple acquisitions over the same area (Balz, 2019; Berardino, 2002; A. Ferretti, Prati, & Rocca, 2000; A. Ferretti et al., 2001; A. P. Ferretti, C.; Rocca, F., 1999; A. J. Hooper, 2006; A. J. Hooper et al., 2007; Werner, 2003).

2.5 ALOS-2

The ALOS-2 is a Synthetic Aperture Radar (SAR), that emits microwave and receive signal from ground acquire data. This satellite mode does not need light to get data images from earth surface such as the Sun. In the SAR mode is and advantage of providing satellite images all days and all nights. The ALOS-2 use transmitting frequency of L-band and receive frequency back with L-band by regardless of clouds and rains. The L-band microwave can reach to plant and vegetation on ground surface. The ALOS-2 can do operation in multiple weather condition. The ALOS-2 has been launched in 2014 and estimate lifetime is 7 years.

PALSAR-2 Specifications

Observation mode		Spotlight	Stripmap Ultrafine [3m]	Stripmap High sensitive [6m]		Stripmap Fine [10m]		ScanSAR Normal		ScanSAR Wide
Bandwidth (MHz)		84	84	42		28		14	28	14
Resolution (m)		3×1 (Rg×Az)	3	6		10		100 (3 looks)		60
Incidence angle (deg.)		8 - 70	8 - 70	8 - 70	20 - 40	8 - 70	23.7	8 - 70		8 - 70
Swath (km)		25×25 (Rg×Az)	50	50	40	70	30	350 (5 scans)		490 (7 scans)
Polarization*		SP	SP/DP	SP/DP/CP	FP	SP/DP/CP	FP	SP/DP		SP/DP
NESZ (dB)		-24	-24	-28	-25	-26	-23	-26	-23	-26
S/A (dB)	Rg	25	25	23	23	25	20	25	25	20
	Az	20	25	20	20	23		20		20

* SP: HH or HV or VV, DP: HH+HV or VV+VH, FP: HH+HV+VH+VV, CP: compact pol. (experimental)

Figure 9 Specification of ALOS-2 (JAXA)

PALSAR-2 is a very useful sensor with high resolution with wide swath and image quality low-noise and ambiguity. The ALOS-2 has a spotlight mode that will allow comprehensive monitoring of disasters by giving users with more detailed data than ALOS/PALSAR. The repetition observation of ALOS-2 was generated by expanding the observable range of the satellite up to about 3 times (from 870 km to 2,320 km) and giving ALOS-2 a left-and-right looking function which very special function.

CHAPTER 3 METHEDOLOGY

3.1 Scope of study

3.1.1 Study area

This research mainly focusses on Samutprakan province, Thailand to be the study area because this area is the most important in term of main port of Thailand and security strategy of Thailand at the same time. Smutprakan located in 13.376150 N, 100.424795 E. Samutprakan Province, with an area of approximately 1,004 square kilometers or approximately 1,040 km^2, is considered the 70^{th} largest province in Thailand covers the Chao Phraya River. This province located in latitude 13 – 14 north and longitude 100 – 101 east. And there are many branch canals separated from the Chao Phraya River The terrain is generally lowland, divided into 3 areas, namely the two banks of the Chao Phraya River. Suitable for farming. In the south near the coast sea water flooded land and freshwater bodies are highly salty in the dry season. There are mangrove forests along the coast that are suitable for aquatic species propagation. The economic value. Samutprakan is one of the highest GDP of Thailand that approximately 2.2 billion US dollar in 2019 (www.samutprakan.go.th, 2020). This province is the main cargo hub of Thailand that consist of ports and airport (Suvrnabhumi the biggest airport in Thailand). Moreover, Samutprakan is facing problem about its environment such as air pollution from many industries, flood from sea level rise, land subsidence from the use of ground water and damage of natural resources. That would be the high concern of land use in the near future of this area to make a plan and estimate the suitable area for long term land use of Samutprakan province. The footprint is presented in figure 10 that cover Bangkok, Nonthaburi, Samutsongkram, Samutsakron, Ratchaburi, Chonburi, Chachengsao, Nakornprathom. The background image retrieved by Google Earth year 2019. This study will benefit to Samutprakan province to make plan of land use in the near future for their residents and industries in this area.

Figure 10 The study area by AOLS-2, Sentinel-1 and CORS stations

Figure 11 the data image acquisition IW ascending mode from 2014 - 2020

Figure 12 two CORS stations in study area

3.2 CORS stations

The two CORs stations from the Department of Public Works and Town & Country Planning (DPT) and Department of Land (DOL) that provide the GNSS data from 2014 – 2020 in term of vertical and horizontal motion to validate with the satellite data set from ALOS-2 and Sentinel-1. The GNSS data sets are verified by Precise Point Positioning (PPP) online named AUSPOS, the Australian government geoscience free site to remove models GNSS systematic errors and provide a high level of accuracy position from a single receiver. The CORS stations provide GNSS data with latitude, longitude, and height from 2014 – 2020, 24 hours per day, 365 days per year. In this study corrected data that relates to data correction from AOLS-2 and Sentinel-1. All data will be the same date each other to make comparative from those three sensors. The data from ALOS-2 corrected from year 2014 – 2020 with 30 images by SM3 operation, OBS Path. The data image from Sentinel-1 corrected with 22 images by SLC, IW, VV+VH. All images have related each other in date requirement. Although the date of requirements is not exactly the same because of the revisit time of Also-2 and Sentinel-1 are 12 and 16 days respectively, they can be compared in time series and some same spot by land deformation and land subsidence in geometry and trend of graph.

Table 1 satellite image collection from ALOS-2

No.	Operation	Scene id	OBS Path No.	Center Frame No.	Date
1	SM3	ALOS2016650260-140913	150	260	20140913
2	SM3	ALOS2020790260-141011	150	260	20141011
3	SM3	ALOS2027000260-141122	150	260	20141122
4	SM3	ALOS2031140260-141220	150	260	20141220
5	SM3	ALOS2037350260-150131	150	260	20150131
6	SM3	ALOS2041490260-150228	150	260	20150228
7	SM3	ALOS2070470260-150912	150	260	20150912
8	SM3	ALOS2074610260-151010	150	260	20151010
9	SM3	ALOS2091170260-160130	150	260	20160130
10	SM3	ALOS2095310260-160227	150	260	20160227
11	SM3	ALOS2113940260-160702	150	260	20160702
12	SM3	ALOS2124290260-160910	150	260	20160910
13	SM3	ALOS2128430260-161008	150	260	20161008
14	SM3	ALOS2144990260-170128	150	260	20170128
15	SM3	ALOS2178110260-170909	150	260	20170909
16	SM3	ALOS2182250260-171007	150	260	20171007
17	SM3	ALOS2196740260-180113	150	260	20180113
18	SM3	ALOS2200880260-180210	150	260	20180210
19	SM3	ALOS2205020260-180310	150	260	20180310
20	SM3	ALOS2225720260-180728	150	260	20180728
21	SM3	ALOS2227790260-180811	150	260	20180811
22	SM3	ALOS2231930260-180908	150	260	20180908
23	SM3	ALOS2252630260-190126	150	260	20190126
24	SM3	ALOS2258840260-190309	150	260	20190309
25	SM3	ALOS2260910260-190323	150	260	20190323
26	SM3	ALOS2271260260 -190601	150	260	20190601
27	SM3	ALOS2285750260-190907	150	260	20190907
28	SM3	ALOS2306450260-200125	150	260	20200125
29	SM3	ALOS2312660260-200307	150	260	20200307
30	SM3	ALOS2314730260-200321	150	260	20200321

Table 2 Satellite image requirements from Sentinel-1

No.	Subtype	Beam Mode	Type	Polarization	Date
1	SA1	IW	SLC	VV+VH	20170323
2	SA1	IW	SLC	VV+VH	20170404
3	SA1	IW	SLC	VV+VH	20170510
4	SA1	IW	SLC	VV+VH	20170907
5	SA1	IW	SLC	VV+VH	20171013
6	SA1	IW	SLC	VV+VH	20180105
7	SA1	IW	SLC	VV+VH	20180306
8	SA1	IW	SLC	VV+VH	20180728
9	SA1	IW	SLC	VV+VH	20180809
10	SA1	IW	SLC	VV+VH	20180821
11	SA1	IW	SLC	VV+VH	20180914
12	SA1	IW	SLC	VV+VH	20190124
13	SA1	IW	SLC	VV+VH	20190313
14	SA1	IW	SLC	VV+VH	20190325
15	SA1	IW	SLC	VV+VH	20190605
16	SA1	IW	SLC	VV+VH	20190804
17	SA1	IW	SLC	VV+VH	20190909
18	SA1	IW	SLC	VV+VH	20200119
19	SA1	IW	SLC	VV+VH	20200307
20	SA1	IW	SLC	VV+VH	20200331
21	SA1	IW	SLC	VV+VH	20200412
22	SA1	IW	SLC	VV+VH	20200506

3.3 Sentinel-1

For the Sentinel-1 images from 22 images, the image of date 20190124 (ascending, IW, SLC, VV) to be a master image and the rest images are the slave images. The image selection was chosen by SARPROZ program as shown in table 9. The Sentinel-1 data images cannot provide the images from 2014 -2016 with ascending, IW, SLC, VV and the limitation of software license.

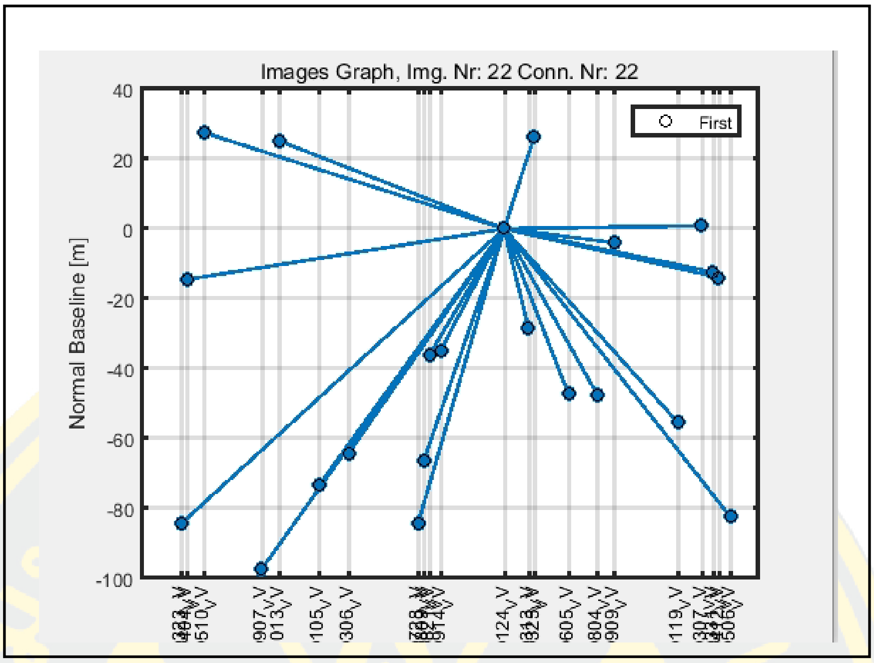

Figure 13 The graph plot of ascending Sentinel-1 images between normal baselines (m) and temporal baselines (days)

3.4 ALOS-2

The images of ALOS-2 retrieved from year 2014-2020 with 30 images by using master image and process in DORIS program. The master and slave will be matched and analysis phase difference. Then, the images will be edited the data and analyses the algorithm of Persistent Scatterers in each pixel in order to calculate the height displacement rate and the rate of land subsidence. The images of ALOS-2 will be analysis land subsidence by mm per year in area of interest in Samutprakan. After getting results, we will receive all data of land subsidence from ALOS-2 and make some comparison with the result from Sentinel-1 in order to find the accuracy or the different that occur between two different satellite images that can be useful for further study from the different methods and different data sources of satellites and program in the same area.

3.5 Data analysis

After we have all results from three difference sources: ALOS-2, Sentinel-1, and Cross stations. All result will be analysis individually form their method to find the most interesting area of land deformation in Samutprakan by using number, graph, and statistic of all three sources. Then, we will compare with two satellite images to find the different point or the same point for making the trend of land subsidence of study area change or not change. After that, the CORS station results will be the referent base stations for two satellite images with a number of latitudes, longitude, and height and find the difference of land movement by ALOS-2, Sentinel-1, and CORS station for finding the relative of arial image and ground station that maybe have some error or different in statistic of latitude, longitude, and height from the last six years of the study area.

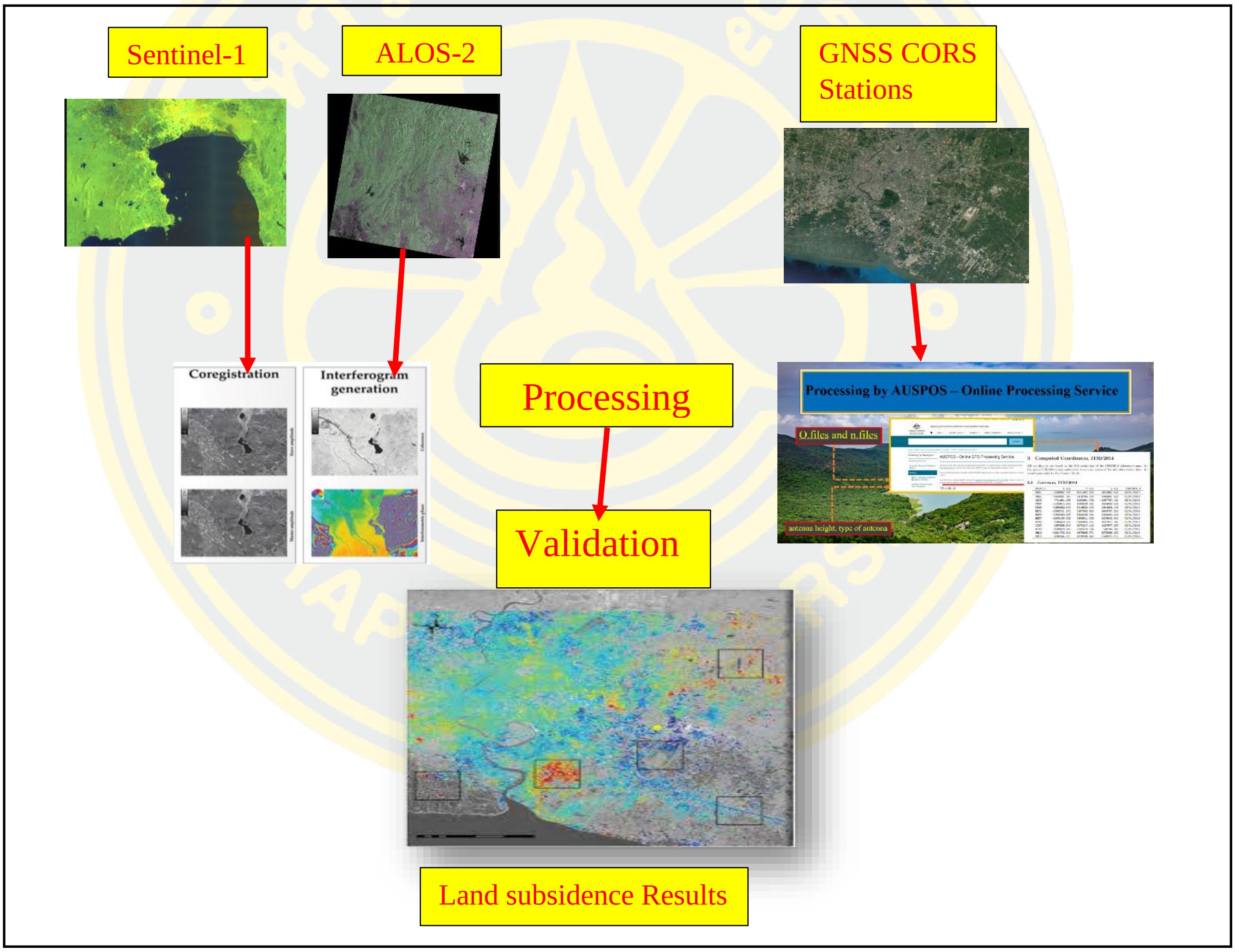

Figure 14 Flowchart of research

3.6 PS-InSAR time-series technique

The techniques of PS-InSAR time-series can identify Earth surface subsidence movement with high precision at millimeter variations in the line-of-sight velocity (Perissin, 2008). the taking of advantage of pixels dominated by a single scatterer without the errors of atmosphere or weather condition and decorrelation. This technique starts from preparation step, pre-processing data, processing (preliminary analysis and geocoding), and InSAR processing, relative with Equation 1 and Equation 2. After that, make the changing atmospheric conditions and also decrease the deformation data. Moreover, the unwrapping of the interferometric phase is a non-deterministic problem that contain a lot of equally correct solutions and can be solved under certain assumptions only. The majority of objective in this study is to measure land subsidence using PSInSAR time-series technique form ALOS-2, Sentinel-1, and CORS station data. The preparation SLC-IW data were used a single-master configuration. Second, a pre-processing data will select mode of the selecting TOPS data, read precise orbit, and co-registration for removing the orbit error for the satellite orbit by comparing the images pixel-by-pixel. Then, the processing generates the InSAR by using external DEM and GCP selection to extract the topographic effect. The final part of InSAR processing is to get rid of the atmospheric delay, noise, and phase unwrap processing in time-series analysis. As a result, the land subsidence got satisfy result. For all processing were support the SARPROZ software (Benattou, Balz, & Liao, 2018; Fryksten & Nilfouroushan, 2019; Perissin, 2016; Perissin et al., 2012; Perissin, Wang, & Wang, 2011) (www.sarproz.com).

3.7 Conceptual Framework

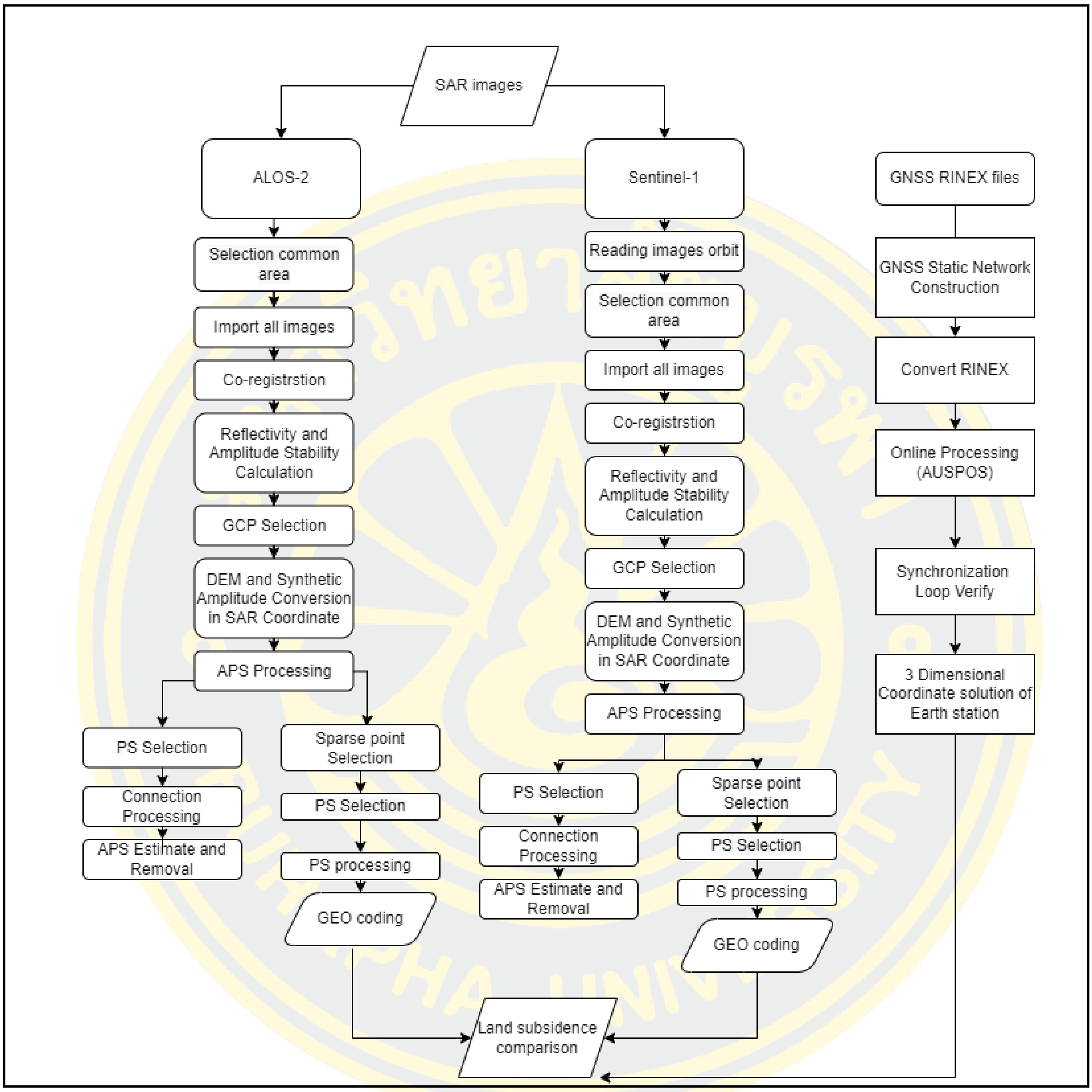

Figure 15 Workflow of the research

3.7.1 Data Preparation

This research has selected the ascending SLC Sentinel-1 data images as C-band that can provided high precision in the interferometric processing in the scope area. The interferogram can happened between one mater image and slave images of all series of the whole image, as shown in Figure 16. The most suitable pairs of SAR interferometry composed a normal baseline and temporal baseline by the master image is on 2019, January 24 for the ascending dataset. The normal baseline of 22 pairs of ascending orbits is between 0-120 meters while both orbits of the temporal baseline interferometry are around 975 days of 2017, March to 2020, May on ascending track. All data preparation were chosen from the relative of data images of ALOS-2 that started from 2014, September to 2020, March. The data set will have some period of time that are related each other, but the revisit time between two satellites is not the same period. The ALOS-2 has revisit date of 14 days, but the time of revisit in Sentinel-1 is 12 days. Those are the results of period of collecting data will get some overlap of date correction.

3.7.2 Pre-Processing Data

All images are Sentinel-1 TOPS data selected with VV polarization and IW2 subs that cover the study area in Samutprakan, get weather, applied precise orbits files, area selection by manual or Google Earth adjusting the scope of area. Then extracted and co-registered the master images and the slave images that can check the example of image by view master. The co-registration will calculate the pair if master and slave’s images in the geometry of the master image. The scatterers of interferograms in both images are carried out using data from satellite orbit and achieved an accuracy of a pixel (Balz, 2019). The Interferogram is generated by multiplying the complex SAR values of the slave image with the complex conjugate of the corresponding master image (Gupta, 2002).

3.7.3 Processing

The Permanent Scatterers candidates (PSCs) (Kampes, 2006) are selected as a low the dispersion of amplitude index for each pixel varies in time. The SARPROZ software automatically downloaded the one arc-second SRTM, as well as DEM 30 m, that covered the study area. The removal of the topographic phases uses the external DEM to similarly the flat Earth. When reflectivity map and amplitude stability index had been finished, then these datasets were geocoded in the mask for sparse and ground control point selection process.

3.7.4 InSAR Processing

In this process consists of the interferogram processing, coherence map generation, atmospheric phase screen (APS), and sparse points processing. The aim of the InSAR processing in the last step is to estimate the atmospheric phase and get the final time series of deformation whereby the measuring from permanent scatterers or stable point. This step, also known as the PS-InSAR time-series technique, is a method to search for the pixels that were based on the stable phase and temporal coherence over a long time. All things considered, the reference point as the same as the reference leveling point (DPT), that special consideration to select the PS-InSAR reference point in a relatively stable and close to the BPLE.

BURAPHA UNIVERSITY

CHAPTER 4: RESULTS AND VALIDATION

This chapter presents and describes all results from the different sources of data consist of ALOS-2 with InSAR technique, Sentinel-1 PSInSAR technique, and CORS stations PPP technique. All results are described separately with statistic and in formation occurred from 2014-2020. The supported software consists of SARPORZ, StaMPS, and AUPOS online software. The intention of this research is to study the land subsidence in Samutprakan province, Thailand that is one of the high-risk areas from flood and land deformation. After making mini research, the result shown that the land subsidence in Samutprakan is interesting for further study by using more satellites sources and GNSS data to make reference each other for suitable results at the end of this research. For all data, we collected from many sectors such as Department of Public Works and Town & Country Planning (DPT) and Department of Land (DOL) with RENIX files and make error verify by Precise Point Positioning (PPP) from AUSPOS online software. The ALOS-2 data we retrieved from output results from Aobpaet, A.(2021) with 30 images of SM3 mode in figure 13. Data from Sentinel-1 were download from the European Space Agency's platforms (ESA) with SLC ascending mode 22 images as shown in figure 14. The Sentinel-1 data were processed by SARPORZ with technique of PS-InSAR that provided estimation of land subsidence, detect several phenomena of land deformation by radar line of sight and eliminate orbit error, noise, topographic effect, and atmospheric delay. The PS-InSAR is very useful for many aspects of land subsidence study.

4.1 CORS Station results and analysis

The CORS stations result were correct by two base stations in Samutprakan between 2014-2020 with continues GNSS receivers 24 hours 365 days. All data were recorded with latitude, longitude, and height from many kinds of GNSS satellites. However, some CORS stations may face some technical problem of data receive from satellites or receivers itself. That were affected of data loosed in some period. In this case, all data still have period of collection time from 2014-2020 by two CORS stations to make the analysis and trend of land subsidence from last six years to be estimate of land subsidence rate in the future.

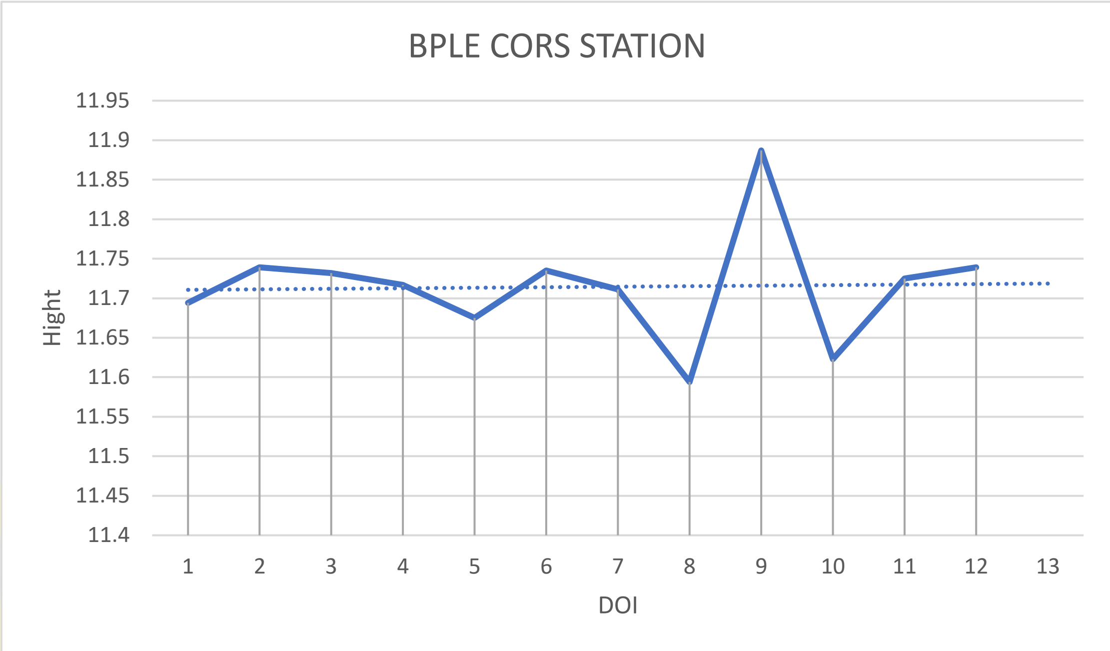

Figure 16 the statistic of height and trend of BPLE CORS station in Samutprakan

Table 3 the data of x y z statistic of BPLE station in Samutprakan shown the movement of CORS station by latitude, longitude, and height in time series.

DOI	Year	month	day	Lat	Long	Hight
1	2014	9	12	13 35 31.28797	100 49 55.62975	11.694
2	2014	10	10	13 35 31.28835	100 49 55.63538	11.739
3	2014	12	19	13 35 31.28856	100 49 55.63249	11.732
4	2015	1	30	13 35 31.28833	100 49 55.63239	11.717
5	2015	2	27	13 35 31.28889	100 49 55.63614	11.675
6	2015	9	11	13 35 31.28800	100 49 55.63309	11.735
7	2015	12	9	13 35 31.28792	100 49 55.63327	11.711
8	2016	1	29	13 35 31.28795	100 49 55.63140	11.594
9	2016	2	26	13 35 31.28821	100 49 55.63705	11.887
10	2016	7	1	13 35 31.28652	100 49 55.63266	11.623
11	2016	9	9	13 35 31.28784	100 49 55.63384	11.725
12	2016	10	7	13 35 31.28731	100 49 55.63456	11.739

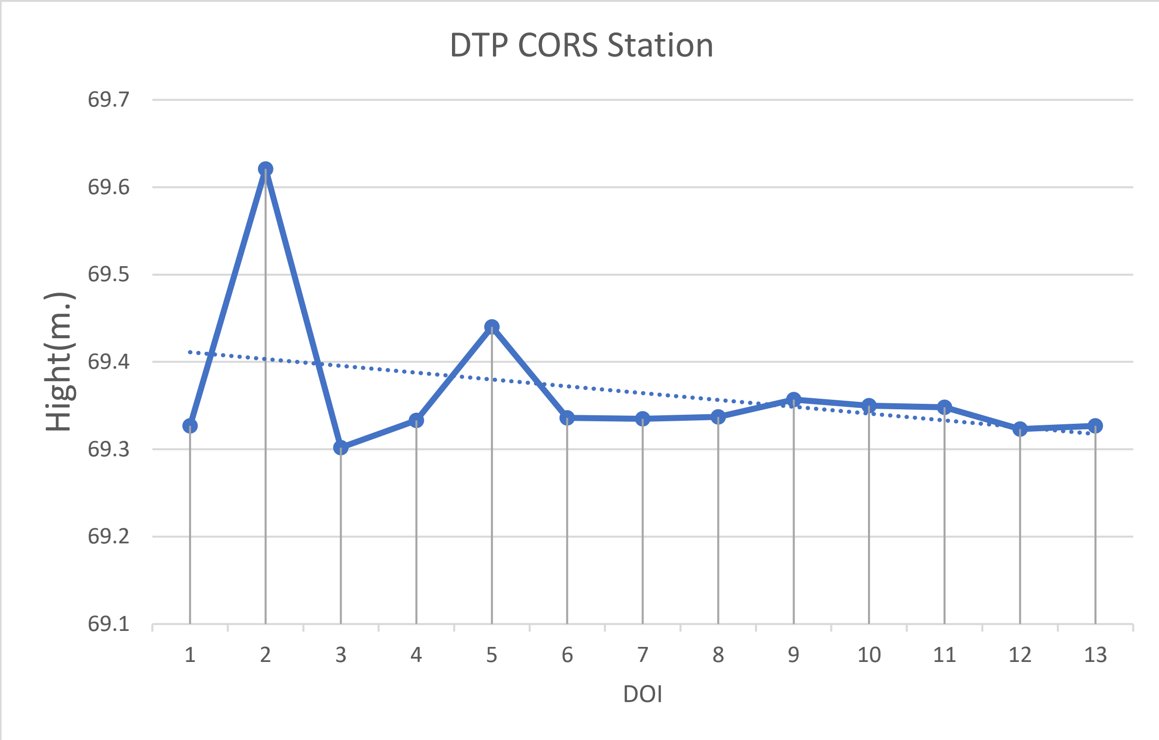

Figure 17 the statistic of height and trend of DPT CORS station in Samutprakan

Table 4 the data of x y z statistic of BPLE station in Samutprakan shown the movement of CRS station by latitude, longitude, and height in time series

doi	year	month	date	Lat	Long	Hight
1	2014	9	13	13 45 24.40454	100 34 23.52987	69.327
2	2014	10	11	13 45 24.40096	100 34 23.52513	69.621
3	2014	12	20	13 45 24.40480	100 34 23.52855	69.302
4	2015	1	31	13 45 24.40378	100 34 23.53063	69.44
5	2015	2	28	13 45 24.40406	100 34 23.53133	69.333
6	2016	1	30	13 45 24.40412	100 34 23.53196	69.336
7	2016	2	27	13 45 24.40399	100 34 23.53202	69.335
8	2016	7	2	13 45 24.40386	100 34 23.53221	69.337
9	2016	9	10	13 45 24.40386	100 34 23.53228	69.357
10	2016	10	8	13 45 24.40389	100 34 23.53244	69.35
11	2017	1	28	13 45 24.40372	100 34 23.53256	69.348
12	2017	9	9	13 45 24.40344	100 34 23.53318	69.323
13	2017	10	7	13 45 24.40353	100 34 23.53327	69.327

From the graph shown above, the first graph of BPLE CORS station that can retrieved data from 2014 to 2016 with GNSS data. The result has shown that the movement of BPLE antenna has move with three directions x y and z. in this study we focused on the change of height by time series in the first line of data started with 13 35 31.28797 N, 100 49 55.62975 E and 11.694 m. The last data has presented with 13 35 31.28731 N, 100 49 55.63456 E, and 11.139 m. From the first and the last line of data shown the different of height 0.555 m. It can be analyzed that the height of BPLE CORS station has gradually raised up 0.555 m. per two year or 0.2775 m. per year. The statistic shown the relation of graph has raised from 2014 and decreased in 2016 to 11.594 m. The graph has raised up again in 2016, Feb and go to the normal base line again with upper trend. In conclusion, the land leveling of BPLE CORS station has lifted by the trend that may cause from some aspects. For the DPT CORS station, the results shown that the movement of its antenna also moved in three dimensions from 2014-2017. Here are the results from the first line of DPT station; 13 45 24.40454 N, 100 34 23.52987 E, and 69.327 m. The last line shown 13 45 24.40353 N, 100 34 23.53327 E, and 69.327 m. Surprisingly, the result of height presented that there is not different from the first and the last data of its height. However, in 2014, Oct the height of antenna has raised rapidly from 69.327 m. to 69.621 m. The difference of 2014, Sep and 2014 Oct were highly different around 0.294 m. in one month. By the way, from the rest trend has dropped down from 2014-2017. Two CORS station presented that raised up and down differently because its location located quite long distant and placed in different zone of Samutprakan province, but during the correction period shown some different value of height. It means that Earth surface at CORS stations have some movement with vertical dimensions. Here are the results of land subsidence of CORS stations in study area.

4.2 ALOS-2 Results and analysis

The ALOS-2 satellite images retrieved data form SM3 mode polarization VV between 2014-2020 with 30 images in the area of Bangkok, Samutprakan, Nonthaburi, Samutsongkram, Samutsakron, Prathumthani by 150 path and 260 of center frame. All data set were processed in StaMAPS software by InSAR technique. The result that we focused on the specific of land subsidence and leveling in the specific spot that relative with the CORS station: Department of Public Works and Town & Country Planning (DPT) and Department of Land (DOL).

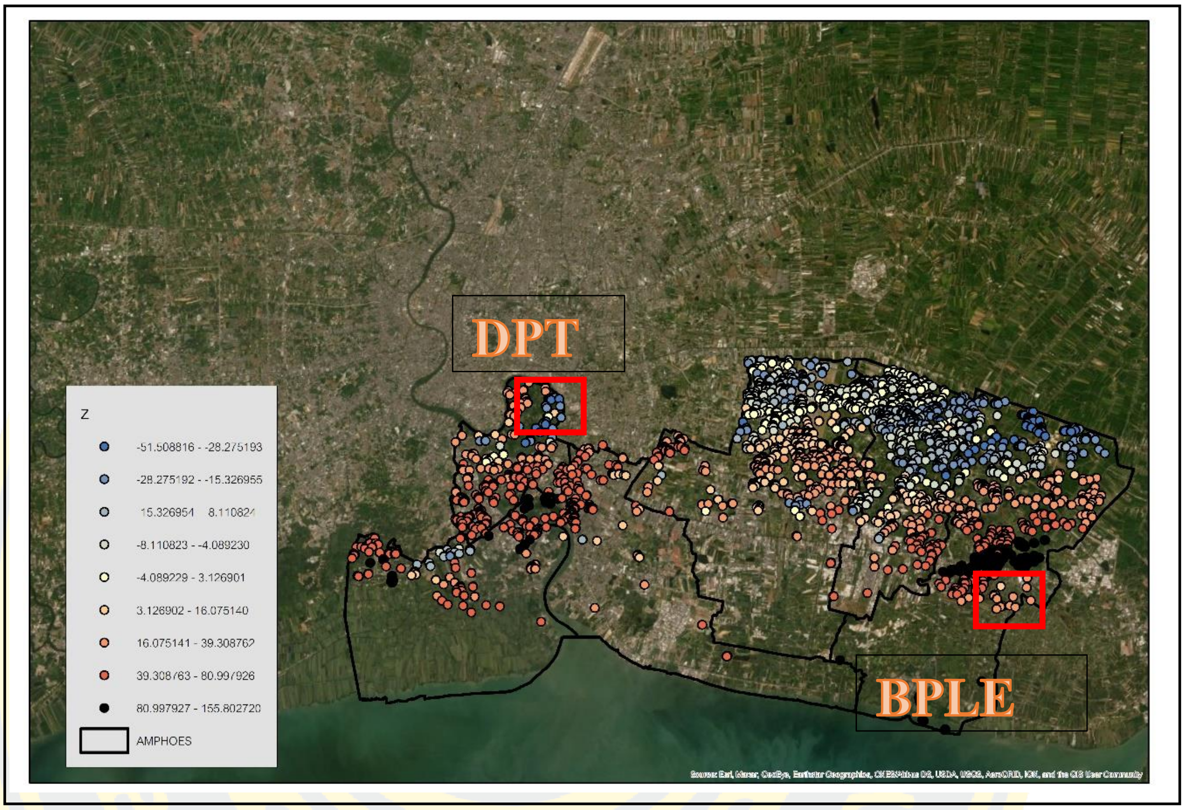

Figure 18 The land deformation spots in Samutprakan

In the figure 19 presented those two interesting spots shown the land deformation related to the position of two CORS station relatively. The results shown the land subsidence at the spot of DPT station has average deformation between -51.506 mm. per year to -28.275 mm. per year. The result of BPLE station presented between 3.1269 mm. per year to 16.075 mm. per year. All the result closely relative from the CORS stations above because at the location of DPT CORS station presented that the trend of land subsidence at its places has decreased gradually. The results from also re-confirmed that the trend of land subsidence at the DPT CORS station is decreasing between -51.506 mm. per year to -28.275 mm. per year. The results from CORS stations shown that the rate of land subsidence 69.4 m. to 69.3 m from year 2014 to 2017. The result number per year should be 30 mm. per year. The results from two different sensors between Satellites and CORS station have very closed each other in unit of millimeters. In the second location of CORS station, BPLE, the results have presented that the average of land deformation are between 3.1269 mm. per year to 16.075 mm. per year. The results from BPEL CORS station presented that the land subsidence number is 11.70 to 11.75 m. from year 2014 – 2016. The result by one year should be 16 mm. per year. The result from ALOS-2 and BPLE CORS station have the same direction in numbers and their trend in raising up trend in BPLE station. In conclusion, the results from ALOS-2 presented that the number and trend of point of interest (DPT, BPLE) go in the same trend. The DPT CORS station has land subsidence trend of decreasing relative with ALOS-2 result that has been shown in figure 19. The BPLE CORS station also has increasing trend relative with the results form ALOS-2 that shown its spot in the same area of BPLE CORS station closely in their number and trend.

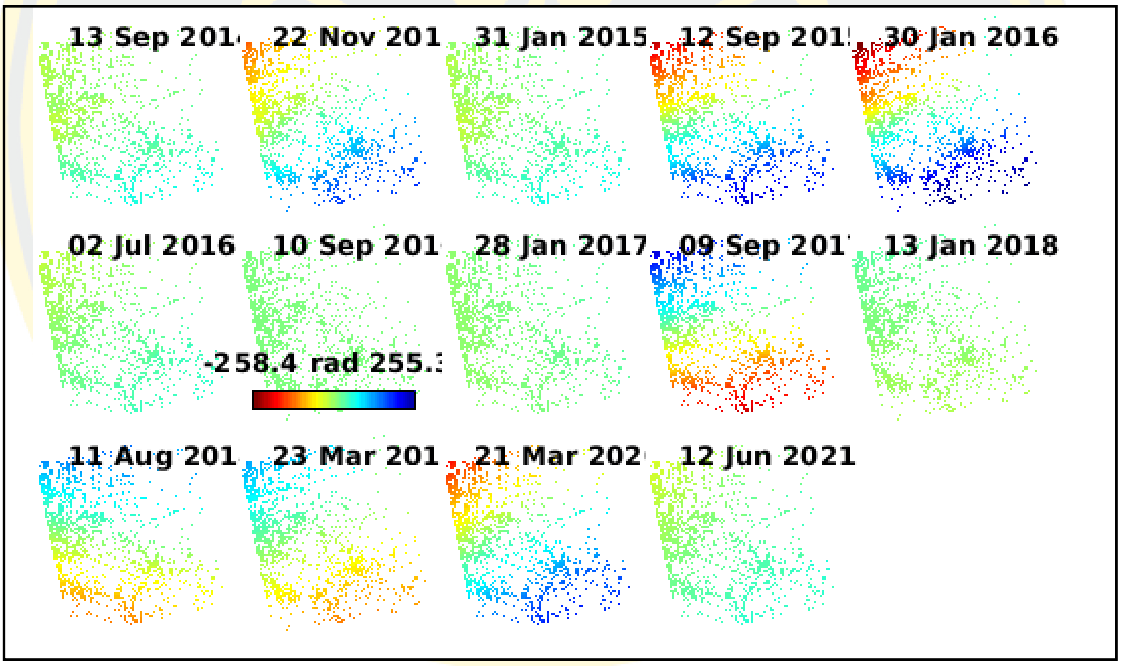

Figure 19 The time series of ALOS-2 results from 2014-2021

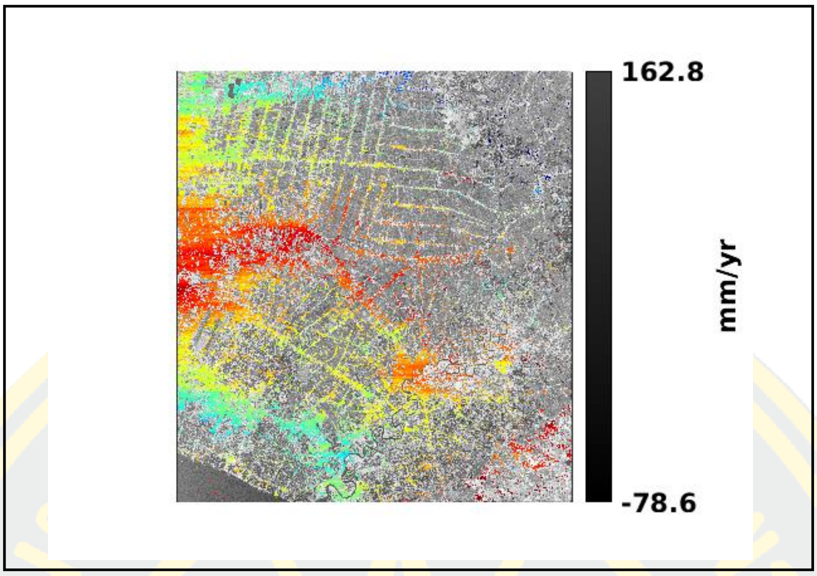

Figure 20 the land subsidence rate show in map mm/year

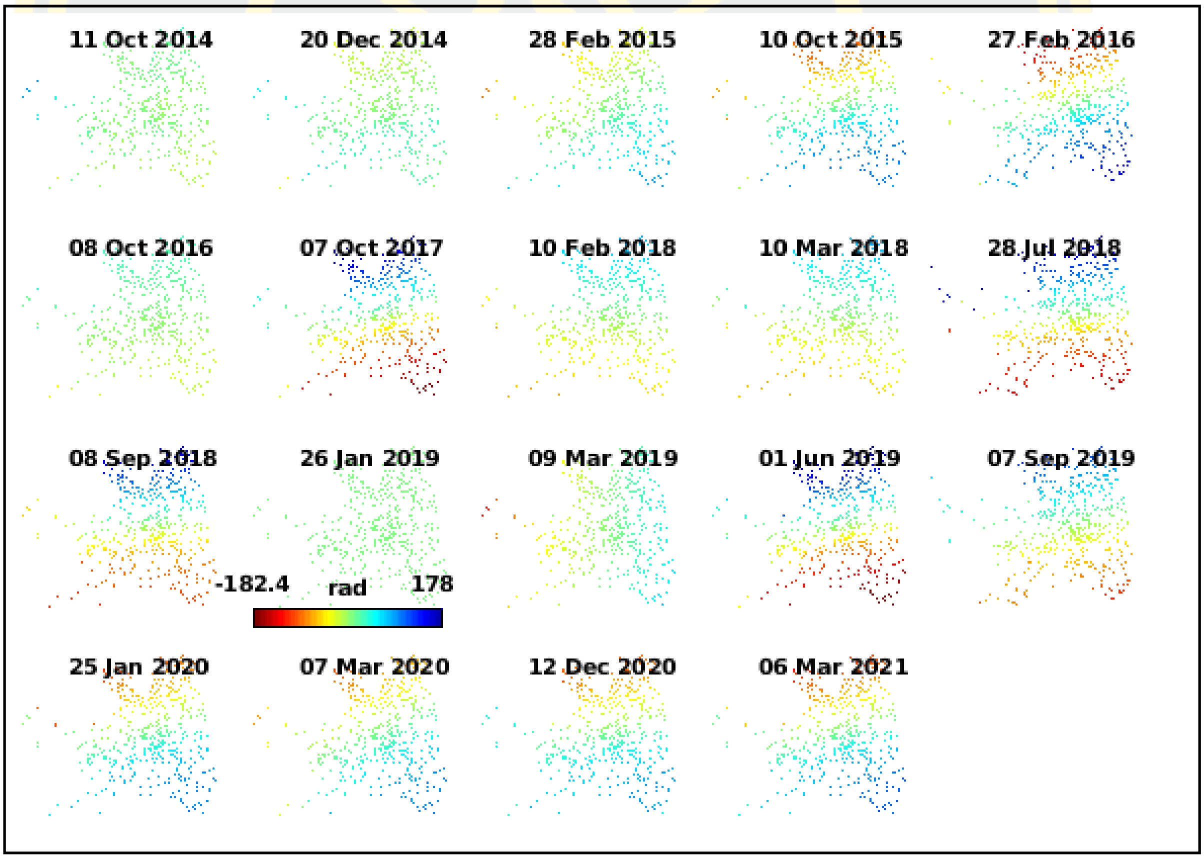

Figure 21 the comparison land subsidence from 2014 – 2021 by ps-plot

From the results from figure 21, the time series of land subsidence in Samutprakan by ALOS-2 results shown the different period of time of 6 years. The movement of land subsidence has been changing many points in Samutprakan that cased from many factors such as the use of ground water in that area, the rainy seasons, drought season, change from human constructions, and land reclamation. The results in figure 22 shown that during the year 2018-2019 the coastal area have leveled down. However, the results from year 2020-2021 the coastal area have leveled up that quite different from the coastal area in 2018-2019. The comparison between 2 different period of time shown that the coastal area has changed their level may cause from the settlement of sand and cray from the sea and change of sea currents and winds.

4.3 PS-InSAR time series analysis

The time series of Sentinel-1 of 22 images ascending mode were classified by SARPORZ software from 2017, March 23 to 2020, May 6. The footprint of sentinel-1 images covers Samutprakan and surrounding province such as Bangkok, Nonthaburi, Pratunthani, Samutsongkram, Samutsakorn, Chonburi, Nakornprathom, Chachoengsao. The PS points are 186,963 points in study that contain the density of PS points of 179 points pre km². The density of points and the land subsidence have shown in figure 22.

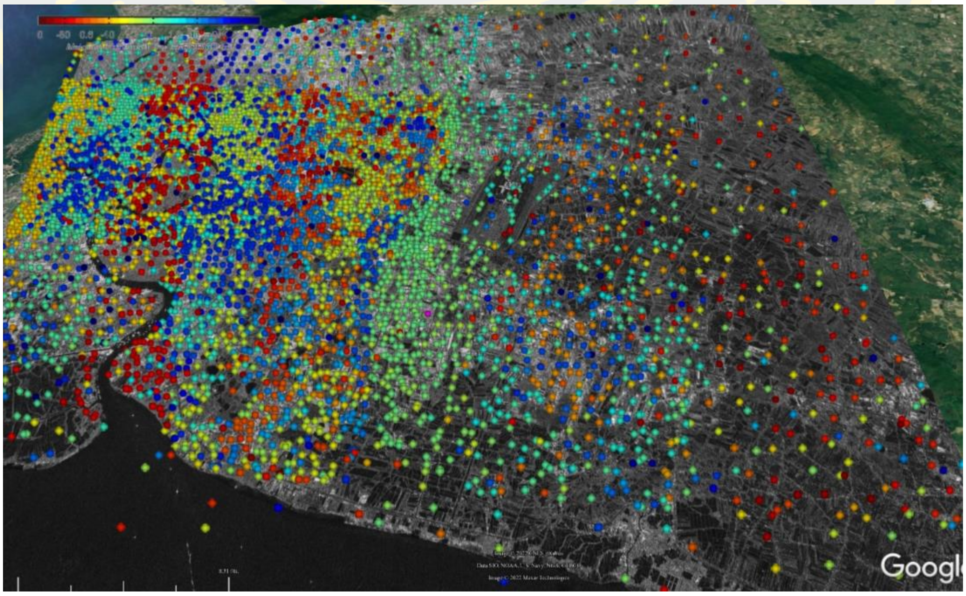

Figure 22 the velocity map of study area and PS points from SARPROZ show in Google Earth

The land subsidence velocity in Samutprakan have shown in map figure 22 presented that there many places in the province that are facing the land subsidence during the last 6 year and in the future. The area near the river got many effects from land subsidence rate faster than the area out of Chaopraya river. The velocity of land subsidence in the red points area around -70 mm/year. The land subsidence of area near Chaopraya river can assume that the land use near the river consist of many constructions and population density more than other areas. In addition, the earth surface near river consists of cray and sand that are easy to have land deformation because of big constructions, the level of water in the river and the sue of ground water with many consumers along the river. For the area far from the river, the PS points present in blue with the velocity of land movement about 40-60 mm/year means that the area the mention above have raise up every. The cause of level up is from the height from construction in the economy city in Samutprakan because Samutprakan province is one of the big economy zones in Thailand, so the PS blue points areas are the level up surface as shown in map figure 22. For the further area, we can identify the yellow and green PS points in both sides left and right. These points indicated that yellow and green PS point areas are the urban area of Samutprakan presented the speed of land subsidence slower than the middle of Samutprakan province. The land subsidence in yellow and green PS points are around -30 to 26 mm/year. Furthermore, on the east of Samutprakan province present the red PS points in the agriculture area. This case indicates that the agriculture activities of farmers in the east area may cause of the land subsidence in the farming area. The farmer may use the underground water or move soil form their places to another places. In addition, the agricultures in the red PS points area mostly are slats farming. The farming use water from sea and underground water for their farming.

To conclude the land subsidence in Samutprakran from the results of land subsidence velocity by Sentinel-1 during 2017 – 2020 in the scale of mm/year, the high risk of land subsidence in Samutprakan is the area near Chaopraya river because the results shown that the land deformation velocity are around -70 mm/year. These results can show the trend of land subsidence in this area to the future are going to be more numbers of land subsidence, so the residents of Samutprakan should be more concerned and think carefully in order to settle down in area near Chaopraya river. For the area that located further the Chaopraya river and middle of economy city, the land subsidence velocity presented in lower rate of land deformation or slowly change in vertical level. This area more suitable for living than the place near Chaopraya river because this area gets impact less impact from land subsidence that middle Samutprakan. The urban area of Samutprakan consist of agriculture area in the eastern part of Samutoprakan. The results shown that the red PS point still present in this area because of the use of underground water and sea water for slat farming.

4.4 Validation Sentinel-1 and CORS stations

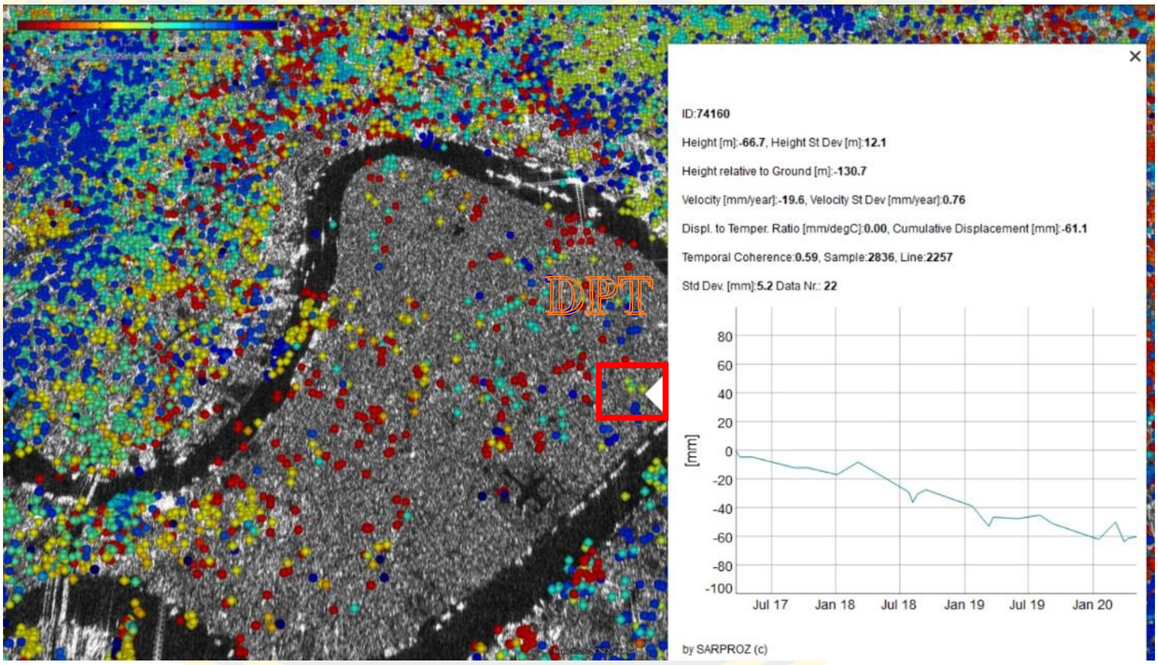

Figure 23 land subsidence velocity of DPT CORS station

The validation between DPT CORS stations can be interpreted from the land subsidence velocity from SARPROZ software by Sentinel- images and GNSS CORS station by AUSPOS. The result from difference sources shown that the land subsidence at the base station from 2014-2020 is -33 mm/year. The result land subsidence velocity from sentinel-1 is -20 mm/year. The different result between CORS station and Sentinel-1 is 13 mm/year. The results from 2 different methods represent in millimeter that are very accurate and presented the trend of land subsidence are level down from 2 sources. Thus, both Sentinel-1 results and CORS station represent the relative number. Although there are some different results in Figure 23, the trend of land subsidence in the ground station and satellite date shown results relatively.

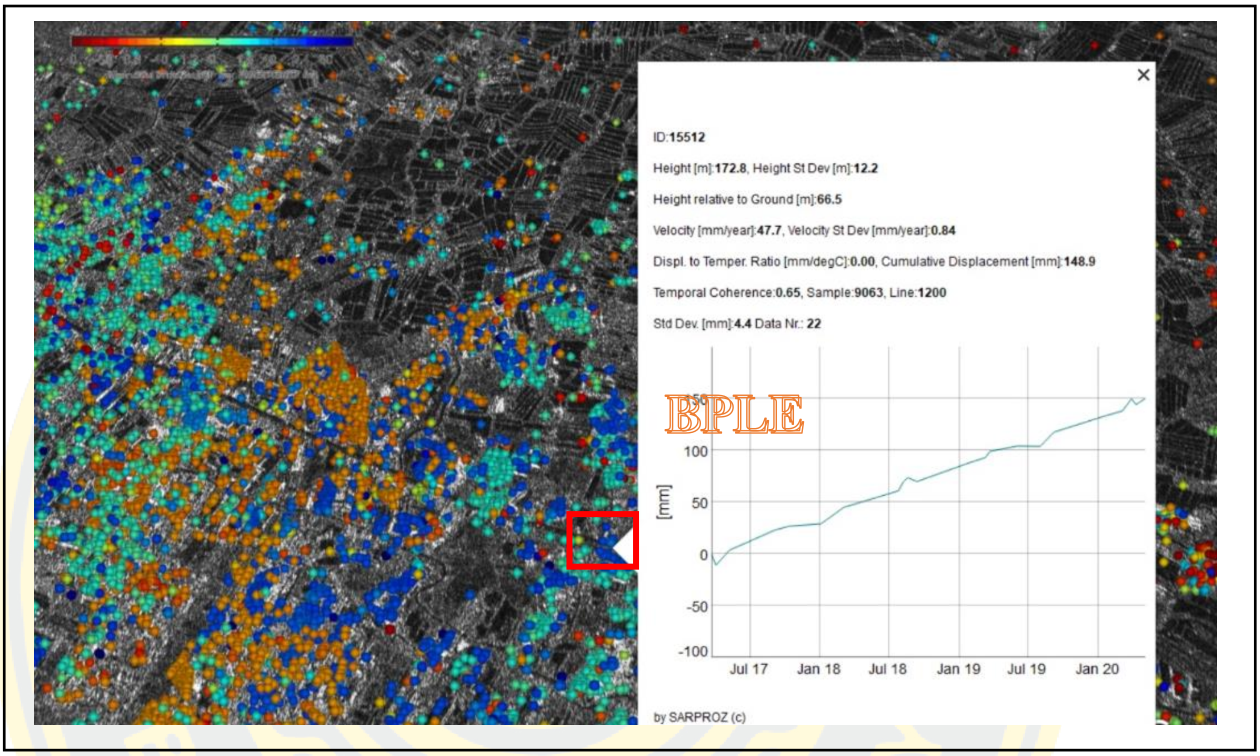

Figure 24 land subsidence velocity of BPLE CORS station

The validation of results between Sentinel-1images ascending mode and BPLE CORS station from 2014-2020 can be interpreted in results of land subsidence velocity in mm/year. Both results retrieved from different sensors and programs. The results of Ps points from Sentinel-1 represented the velocity of BPLE CORS station leveled up 47.7 mm/year in blue points of map in figure 24. The results from GNSS CORS station by AUSPOS online processing is 27.5 mm/year. The difference land subsidence velocity of 2 sources indicated in 20.2 mm/year or 2 cm/year. The trend of 2 sources has relative in results and graph in figure 28. Thus, the result of 2 different sources presented in the same of land subsidence in trend that relate to results of DPT CORS station with level down in Sentinel-1 and DPT CORS station.

From three sources of data, can inferred that the land subsidence in Samutprakan by time series using three different sources Sentinel-1, ALOS-2, and

CORS stations gained the results relatively by trend of land subsidence and vertical line of sight. Thus, all difference sources are reliable and have high accuracy for measure and make reference to find land subsidence of earth surface by In-SAR time series.

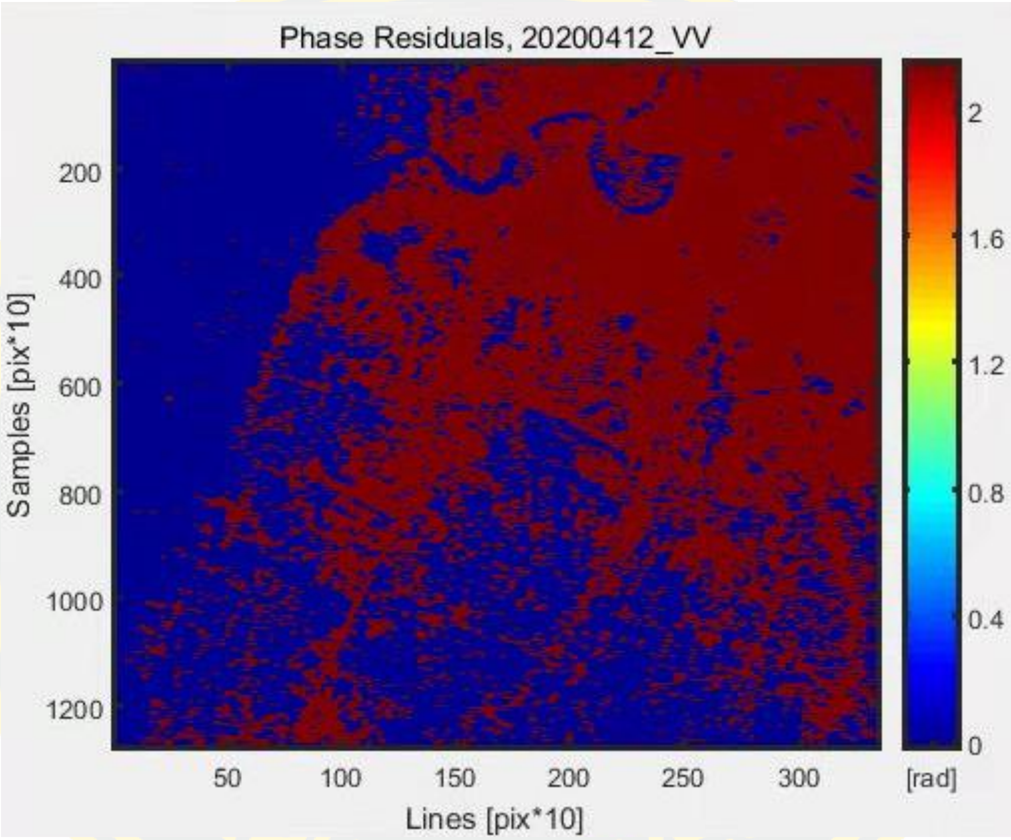

Figure 25 The coherence picture from PS-InSAR of study area

The coherence map from figure 25 shown the area of high coherence in the area that are the construction zone with red color. The area that are not the construction zone gained low coherence with blue color are the area of agriculture, water, and sea. This the high resolution of phase coherence of SARPROZ software by the satellite images of Sentinel-1 X-BAND that can identify the difference phase of earth surface to many types of classification.

CHAPTER 5: DISCUSSION AND CONCLUSION

5.1 Discussion

This research has studied the land subsidence in the most high-risk area in Thailand, Samutprakan by trying to use different of methodology and different sources such as satellite data from ALOS-2 and Sentinel-1 with SAR images that can detect the different of phases of radar energy on the earth surface. There are many studies of land subsidence in many places throughout the world that used InSAR time series of land deformation to study the trend of land deformation in the future for their interest and the change of disasters such as earthquake, volcano eruption, and ground water. In Samutprakan is also the area that is facing land subsidence and sea level raise every year. This research has provided the value, numbers, and trend of land subsidence in Samutprakan in order to know the change of earth surface movement in specific area to concern in some high-risk area of land subsidence. This study also used many different sources to present the numbers of land subsidence in Samutprakan to be various of options and find the most suitable methods and sources for further study.

The results of CORS stations have shown that the trend of DPT CORS station has gradually been decreasing from its statistic in figure 26.

Table 5 height statistic of DPT CORS station

DOI	year	month	date	Hight
1	2014	9	13	69.327
2	2014	10	11	69.621
3	2014	12	20	69.302
4	2015	1	31	69.44
5	2015	2	28	69.333
6	2016	1	30	69.336
7	2016	2	27	69.335
8	2016	7	2	69.337
9	2016	9	10	69.357
10	2016	10	8	69.35
11	2017	1	28	69.348
12	2017	9	9	69.323
13	2017	10	7	69.327

From the result of DPT CORS station, the result of ALOS-2 also presented in the same way of DPT CORS station by getting the statistic in decreasing number from -51.506 mm. per year to -28.275 mm. per year in the same area of DPT CORS station location as shown in table 5.

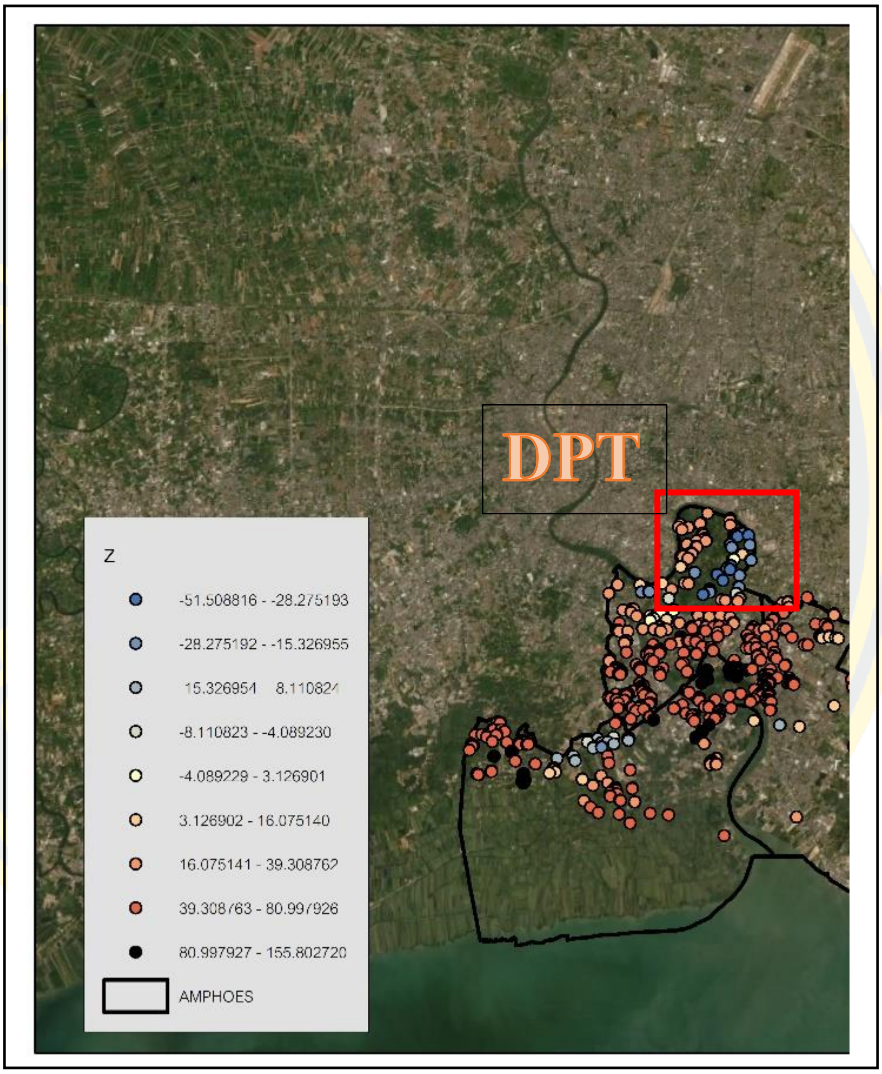

Figure 26 location of DPT CORS station

For the results of BPLE CORS station, the results of land subsidence ALOS-2 gave the relation between BPLE CORS station and ALOS-2. The statistic of BPLE said that the land subsidence has been increasing by 0.555 m. per two year or 0.2775 m. per year as shown in figure 27.

Table 6 statistic of BPLE CORS station

DOI	Year	month	day	Hight
1	2014	**9**	12	11.694
2	2014	10	10	11.739
3	2014	12	19	11.732
4	2015	1	30	11.717
5	2015	2	27	11.675
6	2015	9	11	11.735
7	2015	12	9	11.711
8	2016	1	29	11.594
9	2016	2	26	11.887
10	2016	7	1	11.623
11	2016	9	9	11.725
12	2016	10	7	11.739

The results of ALOS-2 have presented the same direction with BPLE CORS station by the increasing trend from 3.1269 mm. per year to 16.075 mm. per year in the same location of BPLE CORS station as shown in table 6.(Aobpaet, Cuenca, Hooper, & Trisirisatayawong, 2013; Aobpaet, Cuenca, & Trisirisatayawong, 2009; Armaş et al., 2016; Berardino, Fornaro, Lanari, & Sansosti, 2002; Berger, Moreno, Johannessen, Levelt, & Hanssen, 2012; Bert, 2006; Chang et al., 2010; DARDANELLI, LO BRUTTO, & PIPITONE, 2020; El Kamali, Abuelgasim, Papoutsis, Loupasakis, & Kontoes, 2020; Ferretti, Prati, & Rocca, 2001; Hooper, 2006; Hu, Chen, & Zhang, 2019; Kriengkraiwasin et al., 2021; Li, Wang, Michel, & Russell, 2020; Morishita et al., 2020; Noppadol, Giao, & Nutalaya, 2006; Oštir & Komac, 2007; Perissin, 2008; Rizos, Janssen, Roberts, & Grinter, 2012; Shulman, 2020; Werner, Wegmuller, Strozzi, & Wiesmann, 2003; Xiao et al., 2019; Zebker & Goldstein, 1986)

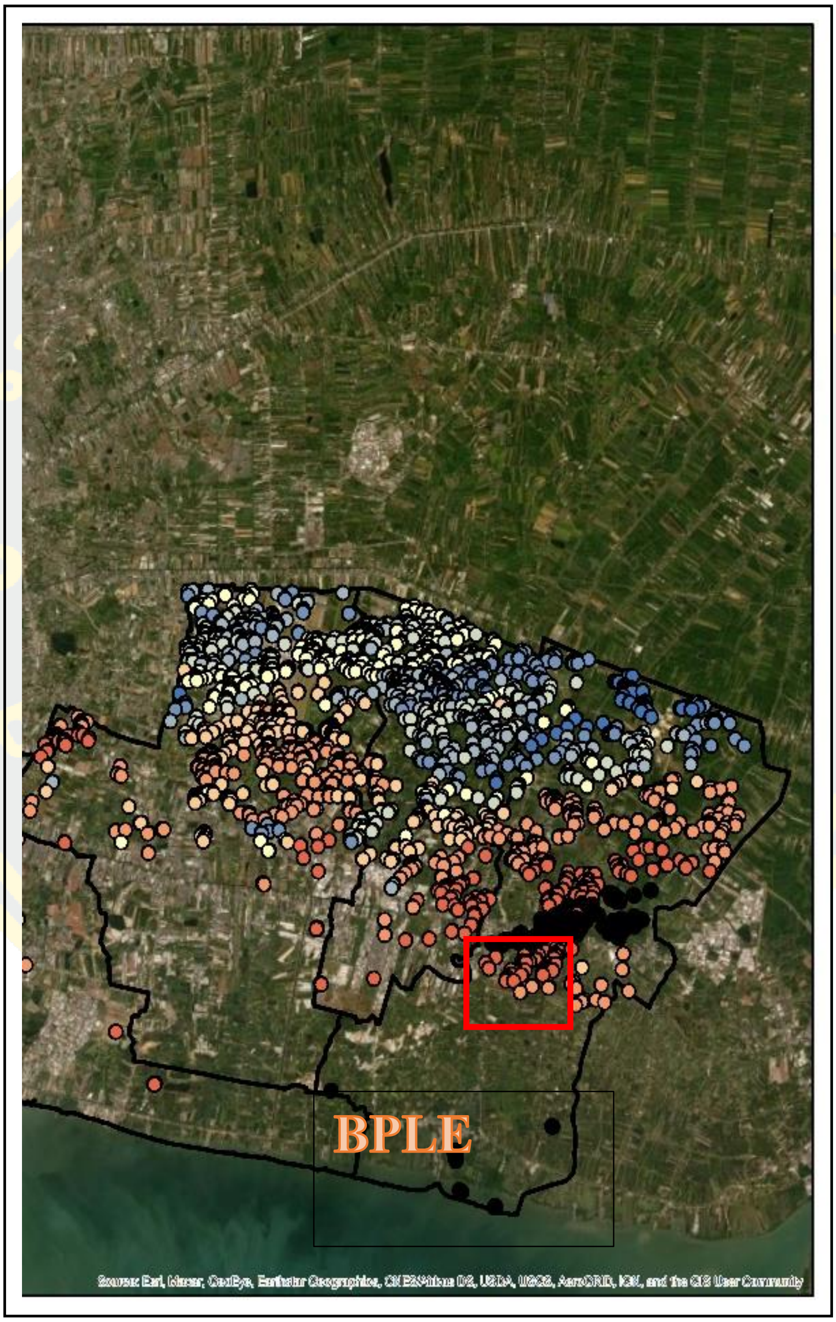

Figure 27 location of BPLE CORS station

To sum up, the results from referent CORS station (DPT, BPLE) have the difference in elevation of up and down in two CORS station that are located. It may have some factors of land elevation in some area. At the DPT CORS station has gradually decreasing numbers by time series because its location near Chaopraya river and get some effect from ground using. The location of DPT is surround by many big constructions such as highway, tall buildings, and underground railways. These factors may lead the land subsidence rates are going down gradually every year.

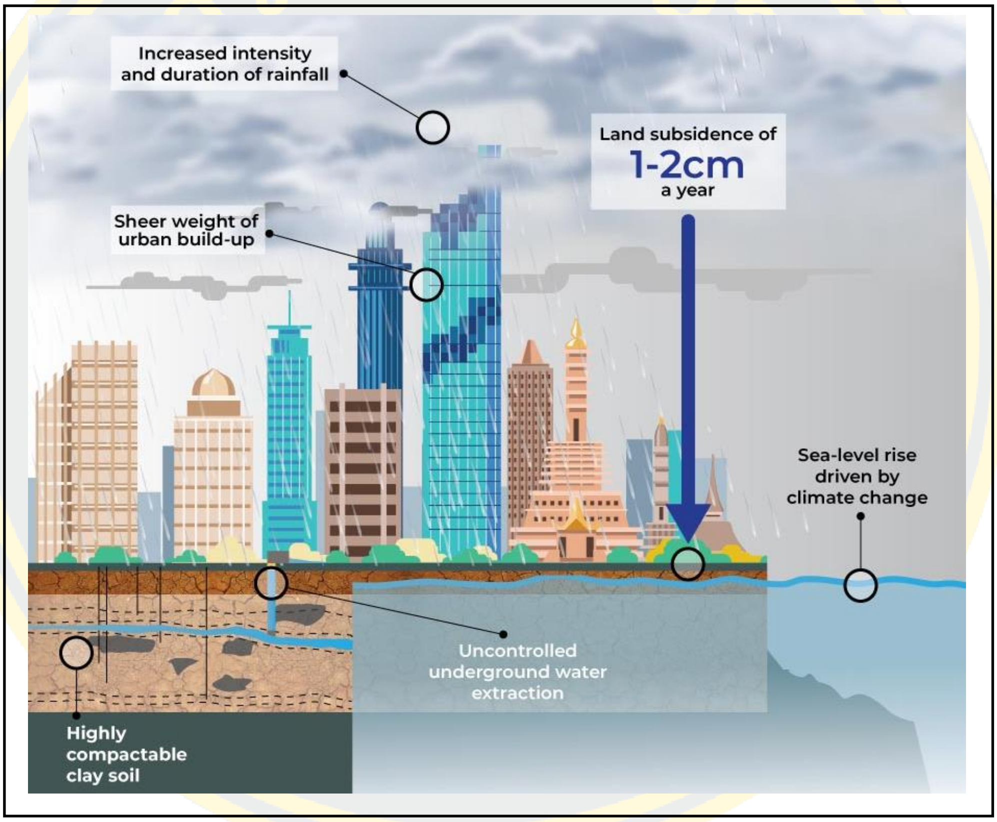

Figure 28 DPT CORS station located on clay soil of Chaopraya river (The AESAN post)

5.2 The performance of PS-InSAR technique from Sentinel-1

The result from Sentinel-1 by using PS-InSAR technique with SARPORZ. The InSAR technique can perform high accuracy in rang of vertical movement. This technique provides instant calculation for user to read graph and numbers of land subsidence from many parameters provided in SARPORZ software. The software provides many parameters for users to change and make many types of comparison on order to measure land subsidence velocity, scattering, phase, coherence from SAR image. The high accuracy is very useful for the users to calculate and make some prediction of land subsidence in their study area in the future. Furthermore, the SARPROZ software can remove orbits error and weather condition to get more accuracy results in millimeter. The PS-InSAR provides the land subsidence in millions of points that is very high resolution of SAR images that is easy to read the numbers of leveling in line of sight. The InSAR technique can work in every kind of weather and all day and night because the SAR technique do not need light the Sun to reflect its energy to satellite's receiver's. The satellite can emit its energy call radar to the earth surface and reflect to satellite antenna. Moreover, SAR technology is the technique that turn on the aperture longer time to receive the reflection of its energy in order to receive bigger footprint in one time that can reduce size of antenna and still get a huge footprint at the same time.

5.3 Conclusion

The study of land subsidence in Samutprankan have reached the purposes and answer the questions after we had got the results and done all analyses. The results from two CORS stations have presented the land subsidence with the change of heights from 2014-2020. The DPT CORS station shown the results of level down with -33 mm/year, but the results from BPLE CORS station shown in level up with 27 mm/year.

From the DPT CORS stations results can be concluded that in the middle of Ssmutprakan and the location near Chaopraya river are facing land subsidence problem very severe because of the underground of this area consist of cray and sand. Moreover, this area located with many constructions and crowned populations.

For the location of BPLE CORS station that located in the urban area far from big city of Samutprakan the results of land subsidence are raising up because the location of BPLE is having some constructions and expand the city form middle of Samutprankan. So, the level of BPLE is leveling up 27mm/year in average.

The study of ALOS-2 had got the same results from with CORS stations by leveling up in the middle of Ssmutprakan and Chaopraya river. The Level of BPLE CORS station has raised by related to the results of ALOS-2 by slightly different in reslluts in millimeters. The figure 23 presented very closed results to the results of 2 CORS stations. These results can be assumed that ALOS-2 InSAR and GNSS CORS station have high accuracy in measuring land subsidence in Samutprakan and Chaopraya basin.

The study of Sentinel-1 by 22 images of ascending mode by PS-InSAR technique and SARPROZ software has presented the results in the same value with ALOS-2 and two CORS stations. The trend of land subsidence in samutprakan has lifted up in urban area and leveled down in the middle of Samutpralkan and Chaoraya river. The coherence map in figure 29 has shown the different types of area in Samutprakan and the figure 26 has shown the PS-InSAR of hundred thousand points of land subsidence velocity in the footprint Sentinel-1 map.

All results have answered of this thesis that want to know the influence of land subsidence in Samutprakan. The influent of land subsidence came from the use of ground water, the city grows up with more populations. These reasons cause the land subsidence in Samutprakan. For the rate of land subsidence in Samutprakan have different rate in different area. In this study we focused on two CORS stations to be the ground base reference for land subsidence by two satellites. The land subsidence rate in the middle of Samutprakan; the location of DPT is going down because constructions, use of ground water, and higher populations. The land subsidence rate in BPLE CORS station is going up because the city from Samutprakan has been expanding to the urban area, so the leveling of BPLE CORS station is having the level up. The different of three sources in results are not highly different. The results from all sources presented in the same trend of land subsidence velocity. The different in numbers of millimeters that reliable accurate.

Suggestions

After experienced the study of land subsidence in Samutprakan by using satellite data and RINEZ files from GNSS CORS stations. The accuracy of results is not different in number of the same locations on the earth surface. The PS-InSAR performed very accuracy in each point and provide many values to get further study other purposes such as land deformation, volcano eruption, earthquake, and landslides because this technique can measure the change of earth surface in millimeter. The data from many of satellites can be easily found from the internet sources. In summary, all sources' data mad methods in this study provided the very good in processing and very high accuracy of the study of land subsidence in Samutprakan. That is useful for land subsidence because all methods in this study presented nearly the same results and trend of land subsidence.

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